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PAPER I.

CONVOYS IN WAR.

BY

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(*Lecture delivered at the School of Military Engineering, Chatham, on 7th January,* 1904).

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CONVOYS IN WAR.

PART I.

ADMINISTRATION AND CAMPS.

THE subject of Convoys is the branch of military instruction which is, perhaps, the most neglected in peace time, because considerations of economy and convenience render it seldom, if ever, practicable to form convoys for the supply of troops operating at manœuvres. Introduction.

In the first place the forces engaged are in the field for such a short time during peace operations, and the area is so limited, that it is not necessary to organize transport on the scale demanded by an army in war; and in the second place, manœuvres take place in populated countries, in which the conditions of fighting are very different from those which obtain in the regions in which most of our wars are carried on.

But it is precisely for the reason that our wars are usually waged in inhospitable countries that the question of the transport of supplies in war acquires additional importance.

In civilized countries convoys, following in rear of great armies to provide for their supplies of food and munitions of war, are merely baggage columns covered by the broad extension of the forces which they follow, and are seldom subject to other molestation than that of small marauding bands or of hostile inhabitants.

It is not with convoys such as these that I propose to deal now; nor will space allow of my dealing with railway and water convoys, which may be considered as separate subjects. I will confine my remarks to transport convoys moving through a hostile country—convoys dependent entirely on themselves for their own security when on the march.

I am afraid that the subject is rather a dry one, and that much that is required for a thorough knowledge of convoy work can only be acquired by experience. But if officers will retain only the main principles and the most salient features of the matter I am about to lay before them, they will, in a campaign, find themselves less unfamiliar, when first brought practically before this question, than they would otherwise be; and a suitable measure for a given eventuality may thus present itself more readily to their mind.

Transport in connection with Convoys.

The subject of convoys is, properly speaking, separate from that of transport, but it is very largely dependent on it; and a knowledge of the capacities and requirements of animals is most necessary to an officer engaged in convoy work, in the same manner as an intimate acquaintance with the horse and his care is essential to a cavalry officer.

METHODS OF TRANSPORT.

I shall, therefore, trench on the subject of Transport only to this extent, and shall begin with the side of the question relating to the animals and vehicles you may have to deal with. Space will not, however, allow of my giving you more than outlines on this subject.

In war between European nations, apart from convoys by water and rail upon which I shall not have time to touch, transport consists almost exclusively of wagons drawn by horses or mules and, especially in mountainous country, of horses, mules and donkeys used as pack animals.

Mechanical Transport.

In future, however, mechanical transport will form a very important feature of convoy work where the nature of the communications will allow of its employment, and when time will permit of the establishment of posts along the routes that convoys will regularly follow. Regular trains were run out thirty miles and more from depôts to more advanced posts during the late war in South Africa, and with great advantage; these trains moved by themselves, carrying their own escort of a few men well protected from sniping. It is dangerous, however, to use mechanical transport over unknown country in the same way as wheeled transport. During the first advance from Kimberley on Boshof an attempt was made to send mechanical transport with the troops, but the roads were not metalled and were suitable only to the local wheeled transport; the mechanical transport stuck and had to be left behind till empty wagons were sent back to ease the train, which came along next morning, fortunately without molestation.

I do not propose to say more on the question of mechanical transport in war, as the subject is a highly technical one; but its development should be watched, as continual improvement in it is certain, resulting in its ever wider application and in increasing possibilities for convoy work.

Wheeled Transport.

The Army Service Corps wagons are excellent where they can be employed. In South Africa they answered admirably for mule draught. As a rule, however, the local wheeled transport is the best suited to the country and to the requisitioned animals which are available to draw it.

In the Red River Expedition the ordinary Canadian wagon was used, carrying 1,600 to 1,900 lbs. In Abyssinia, Afghanistan and Egypt, Maltese carts were largely used. In the American Civil War the ordinary country wagon was employed, with 6 mules drawing 3,000 lbs. nett.

In the late Boer War, the Army Service Corps wagon with 10 mules had a load of 3,000 lbs., often, I fear, exceeded. Ox wagons had teams of 16 oxen and carried 4,500 lbs. Cape carts—a sort of two-seated buggy drawn by two horses—were very useful for short and rapid work with mounted columns, but they only carry about 300 lbs. besides two passengers.

In India there are two regulation carts; one drawn by two bullocks and carrying 960 lbs.; and the other, for light baggage, called the "Light Cart," drawn by a mule or pony and carrying about 700 to 800 lbs. if the load is compact in form. A light sort of cart called "Ekka," drawn by bullocks, is now being tried in Somaliland, but apparently not with much success.

Animals, generally speaking, draw three times the weight they can carry; therefore wheeled transport, when possible, is always preferable.

Horses.

Horses are the animals most universally found in civilized countries, and wheeled transport is, therefore, mainly dependent on them.

The advantages of the horse are that he draws a big load and that he is very amenable. His disadvantages are that the food stuffs which suffice to keep a mule in condition are totally inadequate for a horse, and grain in liberal quantities is therefore an essential; that he is delicate, and therefore more liable to disease and to the effects of climate and hardships; and that he is more expensive to purchase and to maintain.

His ration should consist of at least 12 lbs. of grain and 10 lbs. of hay with a couple of lbs. of bran when available; when hay is not available, he must be given an equivalent addition of grain, and be allowed to graze so that he may fill his stomach.

The horses and ponies bred in South Africa require much less grain than European horses. They can subsist on grass alone, but for hard work require a few lbs. of grain each day.

A horse will draw, on fair roads, up to 1,200 lbs.; but for continuous work 1,000 lbs. is a reasonable estimate.

The occasion for using horses as pack animals seldom arises in the British service. When they are used for this purpose, they should be strong and compact and not too big, and those should be chosen which have done continuous work, as they will more readily resist the effects of hardships on a campaign.

With horses used as pack animals the greatest care must be taken that the pack harness fits and that the load is properly distributed. This rule applies to all pack animals, but more especially to the horse on account of his delicate skin.

The load for a big pack horse goes up to 300 lbs. inclusive of harness, but for long and continuous work or over heavy ground or when on short rations the load should be reduced.

Baker Pasha, when he was fighting for the Turks in Bulgaria in 1877, found the sturdy little horses of the country very satisfactory and rapid when the loads were not too heavy. In the Egyptian Expedition of 1882 the Syrian horses and ponies employed carried packs in a surprising manner, and seemed little affected by heat and fatigue; they also kept in good condition upon barley and upon the broken straw which in the East does duty for hay.

Ponies.

Good ponies from the hill districts of India were used in the Bhutan and Abyssinian Campaigns.

The load for a strong pony is 200 to 250 lbs.

Mules.

The mule is the prince of transport animals. He is as good for draft as the horse, and a great deal better for pack work. He is hardier and more enduring, can eat almost anything, and is far better suited for mountain work. His skin, being harder and less sensitive than that of the horse, is not affected in the same way by sun and rain.

Mules have two disadvantages. The first is that they are more easily alarmed by the noise of firing, and are therefore more liable than horses to stampede; but good mules become accustomed to firing, and I have myself seen mules behaving very well under very trying circumstances of this sort. The second disadvantage is that mules as a rule are born kickers, and are often very obstinate when afraid of man. Remember, in convoy work, to stop all harsh treatment of mules. Whipping only confirms them in their bad habits. When accustomed to their drivers and kindly treated they do their best.

The best mules are those which stand about 14 hands, and which most nearly approach the stamp of a horse. Mares are preferable to horse mules as being better workers and more docile.

The average pack load for a mule is 160 lbs., but strong well fed mules can easily carry 200 lbs.

Donkeys.

Donkeys have pretty much the same characteristics as mules. Their pack load is 100 lbs. without saddle. They are slow and not satisfactory for transport work with troops or with other transport, but on established lines of communication, worked quietly in droves by themselves, they may be useful.

Camels.

Camels are, of course, specially suited for desert work, but they are also usefully employed in all dry climates. They are not well adapted for long and rapid marches, but they are very valuable for the carriage of bulky packages and for leisurely work on lines of communication between depôts.

The load for a camel is from 320 to 450 lbs.; in the Nile Expedition with continuous work the load was 300 lbs. His pace is 2 to 2½ miles an hour. He requires 10 gallons of water a day, and should be allowed plenty of time to graze, preferably in the early morning.

His advantages are that he can go without water longer than horses or mules (though his capacity in this respect has been generally exaggerated); that food need not, as a rule, be carried for him; and that great heat does not affect him. On the other hand he is awkward for loading and unloading, is totally unsuited for wet weather, and in some localities is difficult to feed. He is no good over very rough ground or on very steep gradients.

It should be noted that the manner in which camels have been trained to move has considerable bearing on their utility in different localities. The Sudan camels have been accustomed to being driven in droves, and are therefore more suitable for convoys which march in square formation and for moving through bush, as there are no ropes to get caught up in the thorns. The Indian camels have always been led in strings, and they will not move till they get the tug of the one in front. It is obvious how unsuitable such long lines of camels are to square formation, or to bushy country where the camel's rope will be constantly caught in the scrub which he nibbles on the march. It was also found in Afghanistan that Indian camels were not so good for rough country as mules or the country ponies; but they can be used in mountains where the communications are sufficiently good. As regards the marching of the camels it will be generally found that the system of the country is the most suitable to local conditions.

Elephants.

Elephants are not suitable for long or rapid work. They are of most use for pack or draught work over specially heavy ground, where great strength without sustained effort is required.

Their maximum load is 1,200 lbs., but they can draw three or four times as much. They require water every 24 hours and a daily ration of 200 lbs.

There is often difficulty in supplying elephants with proper food. Those, for instance, which were taken to Kabul by Lord Roberts had to be sent back to India, as the climate was not suited to them in winter and the sugar cane and food stuffs which elephants require were not obtainable.

On narrow roads they cause considerable delay if they break down or die. In the latter case it is necessary to cut them up and to remove them piecemeal, as they cannot be dragged away.

Female elephants are the best to use for convoy work.

Oxen.

Oxen are much better as draught than as pack animals. In countries like South Africa and India they are invaluable, as they have the great advantage of feeding themselves. They are, however, slow and rather delicate, and liable to disease.

An ox will carry 160 lbs. as a pack animal, and will draw 800 lbs. He requires at least 8 hours a day grazing to keep him really fit.

His ordinary "trek" is about 16 miles a day. He stands fire better than other animals.

Carriers.

In some regions of the world only human transport is available. It is most suitable when the carriers work by stages, returning to the same place each night. They have not then to carry their blanket &c.

The loads in Africa are carried on the head, in India on the back, in other places slung on poles between two men or on the two ends of a pole carried by one man.

The loads in China, Ashanti (where women were largely employed) and Zululand were 50 lbs. In Indian campaigns the loads have been 40 lbs., which is the regulation weight in India now.

Carriers should do 15 to 16 miles a day.

They should be organized in companies and squads under their own head men, with superintendents and with officers in command.

One disadvantage of man as a means of transport is that he carries such a small weight; in the Ashanti Expedition of 1895-96, for a force of 1,500 men, over 17,000 carriers were employed. Another disadvantage is that men are always liable to strike work, or they may bolt under fire or desert.

Carriers are, on the whole, the worst form of transport, and are never used when other means of transport are available.

Space on March.

Horses, mules and bullocks occupy a space of 4 yards in column, allowing for the proper distance between animals. A camel occupies 5 yards.

A wagon with 2 horses takes 10 yards, with an additional 4 yards for each extra pair of animals; an ox wagon and team take up 40 yards of road.

Owners of Animals.

It is always most desirable to have the owners of the animals with them. They look after them well and understand their wants and their capabilities; and animals work better, especially under difficulties, with men to whom they are accustomed.

CONVOY SYSTEMS.

Convoys are worked on three systems, *i.e.*, Direct Convoy, Staging, and Meeting systems.

Direct Convoy.

In the Direct Convoy system large sections of transport move from the base, which may be a spot on the sea coast, or a central point in the heart of the country (constituting an advanced depôt), or any point along a line of railway or water line.

The Direct Convoy system is necessary during the first advance of an Army or Expeditionary Force; for the staging system takes time to arrange, and well guarded convoys are the best when travelling through hostile and difficult country. Transport by Direct Convoy is also necessary when a large number of wounded have to be removed, when the movements of the Army necessitate a change in the line of communication, or when the contingency of a retirement involves the easy and prompt removal of magazines.

Staging System.

In the Staging system the entire distance to be traversed by convoys is divided, as much as possible, into equal parts or stages; the same section of transport working over the same ground, going laden, and returning unladen except for sick and wounded.

This system takes some time to arrange; and is to a great extent dependent on the good-will of the inhabitants and on immunity from molestation except, perhaps, by a few marauders.

It is a system with many advantages, where it can be adopted. If troops are compelled to fall back, they do so on established magazines and have not to abandon, it may be, large quantities of supplies and transport.

If the Army be operating from a sea base, where all the supplies cannot be landed at once, the staging system offers the most rapid means of furnishing the force with sufficient supplies to commence operations. Where the communications allow of it, mechanical transport is specially well adapted to this system.

In case of an emergency, too, rapidity is secured; for, with relays of animals on the road, convoys may march day and night, and thus accomplish two or three marches in 24 hours.

Other advantages are those connected with water and grazing; of having the drivers working always on the same stretch of road; of increased rest for animals; and of better shelter being available for man and beast.

Meeting System.

The Meeting system is that by which two sections, one laden and the other unladen, work in conjunction and meet daily at a fixed half-way point, where loads are transferred or vehicles exchanged. With this system drivers and animals return to their respective quarters every night.

The distances of the stages may be greater under this system, as half the work performed by the animals each day will be very light; and this is advantageous where the staging posts are, by reason of water supply or other considerations, rather too far apart for a day's journey by the Staging system, in which the animals have to draw or carry full loads all the day.

The system has, however, the disadvantage that two escorts are required instead of one, and delay and inconvenience are caused by changing loads. This latter point presents difficulties at first, but these can be overcome, and the point of transference of loads is generally chosen where animals would in any case have to be unloaded or outspanned for their mid-day halt. There are, however, with this system, the further disadvantages that there is more chance of petty looting by the drivers or escort, as responsibility cannot so well be fixed, and owing to the constant unloading the stores are more liable to damage.

In Afghanistan, on the line of communications from Peshawar to Kabul, convoys were run on this system. Guards, aided by local levies, manned commanding points along the line and remained in position for certain hours of the day, so that convoys could move with little or no escort. No one was allowed to move away from the fortified posts along the line except during these hours that the guards were out. The same method was adopted in the Bara Valley during the Tirah Campaign of 1896, and in certain cases during the war in South Africa.

"Kuchi" Camels.

In India, on portions of the lines of communications not too much exposed to raiding, "Kuchi" Camels are often employed. This means that a native contractor engages to transport supplies at a fixed rate per weight, and runs his own show without escort. It generally answers very well and they get through all right, possibly in certain cases by the payment of secret tribute.

Timing the Crossing of Convoys.

It is very important, in most countries, that the crossing of convoys should be accurately timed so that it may occur at a suitable spot. Great delay would, for instance, be occasioned were two convoys, marching in opposite directions, to meet in a narrow defile.

As the "Direct Convoy" system is that which necessitates the largest and most complete convoy escort, and as all the measures which should be adopted on this system are applicable, though in lesser degree, to the "Staging" and "Meeting" systems, I do not propose to refer to the two latter again.

Composition of Escort.

The nature and strength of a Convoy Escort will depend on a variety of conditions, the principal of which are:—

(*a*) The value of the convoy and its size;

(*b*) the distance of the enemy, and the numbers with which he may be able to attack the convoy, as well as his weapons, character and method of fighting;

(*c*) the disposition of the inhabitants;

(*d*) the nature of the country;

(*e*) the numbers which can be spared for escort duty.

It is highly desirable that a good number of mounted men should form part of the escort. They have to scout far afield, for two most important reasons:—

Firstly. To prevent the enemy from observing the movements and the strength of the convoy and its escort.

Secondly. To move rapidly to a threatened point. A convoy on the march generally forms a long column, so that it is impossible to completely cover it everywhere with the small number of troops available. It is, therefore, most important that a highly mobile body should be available to travel rapidly to any spot which may be menaced.

It often happens, however, that a sufficient number of mounted troops cannot be spared, and that there are only enough to do the scouting work alone. In that case it is doubly important that the work of observation should be widely and actively performed, so as to give the Convoy Commander as much time as possible to make his dispositions for the safeguarding of his charge.

Infantry are necessary for the main fighting purposes—unless the cavalry force is very strong—and for outpost duties at night.

Artillery is wanted to clear the way in front, and to keep the enemy at a distance on the flanks and rear, if he tries to push in.

A detachment of engineers is desirable to repair or strengthen bridges, or to improve drifts and roadways.

I need hardly point out that in very mountainous, in continuously wooded and, sometimes, in very marshy country, cavalry are of little or no use.

Duties in Camp.

Watering.

Arrangements should be made before the column arrives in Camp for the protection from pollution of the water required for use.

Water guards, when necessary, will be detailed for this duty. It is unnecessary to enter further into this matter, as full instructions on this subject are contained in Sec. 154 of "*Combined Training, 1903*"; but animals sent down to water should be accompanied by an officer, when possible, to see that the tired animals are not galloped down to water and that they are not hurried in drinking.

Where a pond is the only water available, animals must not be allowed near it until the water carts are filled; and men must not be allowed to wash in it, as the pond may be wanted again on another occasion.

Take every opportunity of watering animals on the march. Oxen only require water once a day, but they will not water till the sun has been up an hour or two, if the water is at all cold.

Sanitation in Camp.

Full instructions on sanitation are also contained in Sec. 157 "*Combined Training, 1903*," but too much emphasis cannot be laid on the necessity of keeping the camp as clean as possible, even if it be used for one night only. Tired men profit by the dark to foul the camp in order to save themselves a little trouble. Natives are particularly bad in this respect, and are especially lax about leaving the refuse of animals and birds which they have killed lying about all over the place. The camp may be wanted again, and it will be unfit for use if strict discipline is not maintained as regards sanitation.

Latrines should be dug the moment the force arrives in camp, so that there may be no excuse for polluting the neighbourhood of the camp.

Remember that more men are killed in war by disease than by bullets, and that the offence of a Commanding Officer who is careless about the hygiene of his men is little short of murder, because he is certain to lose men by reason of his neglect.

For cases of fouling camp, severe punishment is absolutely necessary.

Care of Animals.

The Commander of a Convoy should insist that the proper care of their animals should be the first occupation of officers and men concerned on arriving in camp, If they are not properly watered, fed and groomed, loss of animals is sure to result, with probable delay to the convoy. Transport animals are precious on service, and every care should be taken to keep them fit and serviceable.

All officers concerned should make sure that the harness and saddles fit the animals, especially as regards pack-saddles. They should see that the loads are properly packed and distributed, or sore backs are sure to be the result.

Pack animals should never be kept standing with their packs on, if it can be helped; it is more tiring for them than marching. The same remark applies to mounted men, who should get off their horses at every halt.

Animals should be allowed to graze as long as possible, and on every possible occasion they should be saved in every possible way.

It is best to have loaded animals carrying full loads, and as many spare unloaded ones as possible, rather than to ease them all a little by giving them all light loads. In this way all the animals can get a good rest in turn.

Leaving Camp.

Commanding Officers should be held responsible that their camps are clean when their corps leaves. This can be done, but firmness is required.

It is often desirable, especially if part of the force has moved off in the dark, that an empty wagon should be left behind with the rear guard, to bring on articles of equipment, ammunition, &c., which may have been left behind. The rear guard should, for this purpose, detach a party of men in extended order to march through the camp and search it carefully after the main body has left.

Grass Fires.

When the camp is pitched in thick dry grass, it is most important that strict orders should be given about lights and fires. No matches should be struck, as casual men throw them thoughtlessly into the grass.

Kitchen fires should only be lit under proper control, with several men standing by with sacks ready to put out a conflagration, and sufficient space should first be cleared before the kitchen fire is started.

These precautions may seem exaggerated ; but frequently, with the grass dry and high and a good wind blowing, I have seen a very near approach to a catastrophe to animals and wagons. In fact, in several instances in the late war a number of animals were killed in this way, as there was no time before the fire reached them to unyoke or untie them from the wagons to which they were attached.

PART II.

TACTICAL CONSIDERATIONS.

Convoys Halted.

We now come to the tactical questions connected with the conduct of a convoy. I do not propose to deal with convoys in regions where no attack is to be feared, or where they are covered from serious molestation by friendly troops. They are, then, properly speaking, not convoys but baggage trains, the senior Army Service Corps officer being in command and the escort consisting merely of a small number of troops for police purposes.

Therefore, devoting our attention solely to convoys liable to attack from a more or less formidable force of the enemy—and this would generally be the case in an enemy's country—we will first consider the measures that should be adopted for the security of the convoy when halted and in camp.

Choice of Camping Grounds.

As regards the position which should be selected for camping, the three main points to be considered are :—Security, Water and Sanitation.

The conditions for Security depend principally on the character of the enemy.

Where artillery fire may be expected—a contingency which would seldom happen in European warfare, but which more than once occurred in the Boer war—the reverse slope of a hill not exposed to the enemy's fire, or a hollow not too large, should be selected. When there is no danger of artillery fire, the summit of rising ground is suitable.

Cover from view is most desirable, but it is essential that the heights immediately commanding the camp should be picqueted. Flat open ground with a grazing fire all round—especially against an enemy who may creep close up in the dark—affords a favourable site provided it is dry.

The worst position—against an enemy armed with modern rifles—is that on ground which is dominated by commanding features too distant and extensive for occupation by the outposts of the convoy escort but still within sniping range, *i.e.*, 2,000 to 3,000 yards. In guerilla warfare, such a position as this is the worst imaginable.

The only remedy in cases where circumstances do not allow of the choice of a better position is to leave before daybreak, so as to get clear of the commanded ground before daylight. The early start will in any case probably allow of flanking parties of the escort occupying the dangerous heights, at any rate on that side of the valley along which the convoy will travel.

As regards the question of Water, it will often be found that a site offers itself which, though advantageous in other respects, is in a position tactically unfavourable, such as the one I have just described. In such case the advantage of proximity to water must be sacrificed to safety, even though the animals and water carts may have a couple of miles to go to get water. It may even be found necessary to water men and animals at the last available opportunity, and to camp without water some miles beyond, in a secure defensive position. Of course, such a course would be avoided if possible, but it was frequently the only alternative during the late war in South Africa.

The worst position for a convoy camp in a savage country is in broken or bush-covered ground, where the enemy can creep up close. Under such conditions incessant vigilance, the clearing of as much space as possible immediately round camp, and a good use of spies, who will give notice beforehand of a projected attack, are the best safeguards.

In war, especially when the camp is only for one night, the question of Sanitation must give way to the other two in the selection of the camping ground; but it is always a very important point, and it increases in importance with the duration of occupation of the camp.

Protection of Camp.

We come now to the actual formation of the camp, and the dispositions for its security.

Against a civilized enemy it must be assumed that a convoy will only be exposed to the attack of parties which will be no stronger than, if as strong as, its own escort; for if the enemy be stronger and determined, the escort, tied down as it must be to a strict defensive and labouring under every disadvantage, would have little chance of eventual escape.

Such parties, therefore, as are likely to molest a convoy camp are best kept away by strong picquets posted well out, say 800 to 1,200 yards, in good and, if possible, well-concealed positions, which should be strengthened, as time allows, so as to afford cover and security from surprise.

These outposts should be assisted, when necessary, by intelligent patrolling and, when possible, by native spies. A few sentries round the perimeter of the camp would then be sufficient watch for the camp itself; but in India, where rifle stealing by individual marauders is very prevalent, sentries close together all round camp are necessary on dark nights, and every possible precaution to prevent rifles being stolen should be adopted. It was remarkable how well the last-mentioned method answered in the late war; I do not know of a single case in which the Boers tried to rush a camp before they had surprised one of the commanding positions held by the outposts; they had the greatest objection to placing themselves, either by day or night, in a position where they might be caught between two fires.

It must be remembered, however, that, in suggesting this system of outposts against a civilized enemy, it is assumed that the numbers of the convoy escort will be generally very limited, and that a complete chain of outposts, such as would be posted to guard a large force in the face of a hostile army, is here out of the question. The point is how to make the best use of the usually small numbers available for this duty.

Unless the convoy escort is very weak in infantry and disproportionately strong in mounted troops, the latter should not be employed on night outposts. The mounted troops have arduous work to perform on the march, scouting widely to front and flanks, and both men and horses require rest if they are to efficiently perform their special duties next day. It may, however, happen that it will be of great importance to hold a somewhat distant position in order to prevent the enemy from sniping or observing the camp, and that it may therefore be desirable to place a detached post there; in such a case it would be best furnished by mounted men.

Formation of Camp.

The actual formation of the camp itself, when operating against this class of enemy, is not of very great importance, but it should fulfil the following conditions:—

(*a*) It should be compact and, if possible, hidden from view;

(*b*) the wagons should be so disposed as to facilitate easy and orderly moving off in the morning or, possibly, at night. Ammunition wagons should be parked separately, under special sentries;

(*c*) the troops forming the escort should be kept clear of the convoy itself, and should be camped in favourable positions just outside it, the infantry covering the other arms;

(*d*) the troops should be camped or bivouacked in the places from which they can most conveniently fall into their proper positions on the following day—positions which are generally taken by roster, so as to equally apportion fatigue and danger;

(*e*) transport officers should camp in their own lines.

The roadways, if such exist, must be left clear.

When time admits, the escort should make a line of defence by digging shallow trenches at suitable places along the perimeter, just inside which the troops will bivouac or camp, so that they can occupy the trenches on the first alarm and without confusion.

Against a savage enemy a zareba or enclosure should be formed, protected, when possible, by barbed wire, thorny bushes or any other obstacles available. The wagons are best parked in the shape of a square or rectangle, the axles being as close to each other as possible. The official book on "*Combined Training, 1903*," states that, except on the rear face, poles and shafts should face outwards to facilitate driving off next morning, but if the escort be weak, and a rush by the enemy may be expected, it is better that the shafts should all be inward. The defending force, in such case, is camped inside the wagons; but if the escort be sufficiently strong, it is always best that it should be clear of the animals and non-combatants and outside the wagons, though within the line of artificial obstacles and, when time and soil allow, in trenches. If the escort be not sufficiently strong to cover each face of the square, it may be posted in protected bastions at opposite corners, so that each bastion commands two sides of the square or rectangle.

This last formation has been specially recommended when the convoy consists of pack animals; but with camels, which are not subject to alarm through firing, it is better for the troops to be inside the square under the protection of the animals, from behind which the men can fire and more easily stop one of those terrific rushes which have always constituted the main form of fighting of the inhabitants of the desert.

In the case of a square or zareba, the question of outposts outside the camp depends on the nature of the country, and is often a very difficult question.

Where, as must necessarily sometimes happen, the camp is formed in a savage country covered by thick bush, it becomes more than doubtful whether outposts pushed out more than a few yards are advantageous; they are, in the first place, very likely to be surprised and cut up, and, if not actually rushed, they will be driven in on the zareba and so impede the defenders' fire, as happened near Suakim 20 years ago. In such a case, however, mimosa bushes and scrub are generally available on the spot for the construction of an obstacle that will stop the first rush of tribesmen; but it is necessary that the troops should bivouac where they will fight, and that they should lie on the actual ground from which they will fire, with their rifles ready by their side.

An open field of fire of at least 100 yards should be obtained by clearing or burning the bushes, grass, &c. round the camp.

Whatever formation of camp may be demanded by circumstances, it should be remembered that inlying picquets should always be detailed to meet a sudden emergency, either about the camp itself or to support a threatened outpost. These picquets, generally placed on each side of the camp, would usually consist of a company, half a company or a section, according to the size of the convoy. The men on inlying picquet should sleep with equipment and boots on, and be in every respect ready to fall in at a moment's notice to fight.

The strength of the escort will determine whether a general reserve can be formed in addition to the inlying picquets, but it is advisable to have one, if possible, and it is often even better to have small local reserves at different points. It is often a good arrangement for each company to have its own defined section of the perimeter, the tents or *tentes d'abri* being pitched parallel to it, with the exits to the side so that the men can get out to their posts quicker. In addition, a general reserve is of advantage to meet any serious emergency.

In the case of a convoy halted for a rest during the day, the orders are very simple:—

The convoy will be parked in the best position immediately available for defence, and advanced, rear and flanking guards will all remain out, just as if they were on the march, acting as outposts during the halt. It is necessary, however, to make sure that this arrangement is rigidly adhered to. Troops forming escorts to convoys are usually a scratch lot, and those in rear and on the flanks are very apt to come in because they want their dinners, and my experience has been that officers are just as bad as the men in this respect. I constantly had to find fault in this respect with Details temporarily attached for duty with my convoys in South Africa, and it required constant watchfulness to guard against the recurrence of this particular form of slackness.

Where the halting place is in a good defensive position, and when a good view can be obtained in every direction, it is of course possible to leave mere observation posts during the day halt, as outpost duty should never be made more harassing than is absolutely necessary; but the parties responsible for security should never be allowed to decide this question for themselves, and should on no account withdraw any of their force without orders. Where their work has been long and tiring they may be relieved by fresh troops, but the relief must in all cases be formally and correctly carried out.

When the march between camps is a long one, it will generally be desirable for a convoy to halt and outspan in the neighbourhood of water for some hours during the day's journey. This halt is especially necessary for oxen, which will not water early in the morning or after dusk and which take a long time feeding.

The start from the halt should be so timed for the different units and sections of the convoy that as much rest may be gained for them as possible, care being taken, however, that no gaps occur in the column of route after the head of the convoy has moved off.

CONVOYS ON THE MARCH.

Principal Rules for Security.

There are a few golden rules to be observed by the Commander of a Convoy moving through an enemy's country, and I should like to impress them on you before dealing more generally with the measures regulating the conduct of a convoy on the march.

(1). He should never allow his convoy to start before the outposts have been relieved, and before the troops have moved to their respective positions on the line of march.

(2). He should make sure:—that all the troops, and especially the mounted troops scouting far out, have been made acquainted with the direction of the march and with the roads which the convoy will follow, with the position of the proposed halts and next camp, and with the latest information regarding the enemy;

(3). That the animals have been watered and fed, when possible;

(4). That the convoy itself, or at any rate that the whole of the section of it which has to march first, is ready to move off punctually; and that it is drawn up, when possible, at a convenient spot at the head of the camp, but within the line of outposts.

When it is desirable for the convoy to move at dawn, the question of punctuality is not an easy matter where civilians and natives are concerned. I had a good deal of experience at this sort of work, and

I found that the only plan was to have them all roused together. Pack animals should not, however, be loaded before their turn comes for moving off. It should be noted that the Boers' favourite hour of attack was at first daylight, and that it was, therefore, advisable to have the whole convoy ready to start at that time, so that if attacked it might be able to conform in mass to any movement of the fighting force.

(5). He should never, when there is the slightest chance of an attack, send on in advance, in order to save time, any portion of his force, with the intention of catching it up later with the more mobile sections of the convoy. Such a measure means, of course, great prolongation of the length of the column and division of strength. An intelligent and active enemy—such as the Boers were—will certainly seize the occasion if he is in the neighbourhood, and an independent convoy, once it has left the base, will seldom know much of the enemy's movements.

In the late war, this slack method several times led to most serious consequences, the most notable instance being that in which one of our generals, towards the end of the campaign, sent on his ox convoy some miles ahead with a portion of his fighting force as escort. He was attacked by the Boers, who, unknown to him, had concentrated close to him during the night. With his column stretched over several miles and weak at every point, the British commander was badly defeated, with complete loss of his convoy and of many men. It is true that a portion of his irregular troops behaved badly—but it is very doubtful if he would have met with any reverse if his whole force and his convoy had been properly concentrated.

(6). Where there is any chance of a convoy being attacked, the whole of the escort should have moved into their marching positions before daybreak, and every animal and wagon should be ready to start.

One can easily understand how important it is for the whole force to be ready to fight at daylight, with the convoy ready to move and with the animals under proper control. A convoy is helpless enough, in any case, against a strong attack ; but if the troops are not in fighting order, and the animals not packed or inspanned, when close firing begins, the inevitable confusion makes the task of successful defence infinitely harder, and at the best there is sure to be serious loss of stores and equipment, and perhaps of stampeded animals.

(7). The advanced guard must not be allowed to dash ahead. It must understand that it should conform entirely to the pace of the convoy; its Commander should halt at once on his own responsibility when he observes any hitch in the progress of the column; and if he thinks it desirable—and the Convoy Commander be not on the spot—he should cause the wagons in front to park up. He must be instructed always to send word to the Convoy Commander when he has thus halted, and again when he once more moves on.

(8). The Commander of the Convoy should insist on the roadway being kept clear on one side, when the breadth of the road allows, so that officers and orderlies, guns, &c., may be able to move freely and rapidly along the whole length of the column.

(9). The convoy should not approach within rifle fire of a defile until it has been well reconnoitered, and then it should push through without halting till it is clear of the defile. The enemy when driven off should not be pursued.

(10). The advanced guard should never halt at the farthest limit of the proposed camp, but should push forward and reconnoitre the ground well to the front; and there should be most positive orders that all the troops covering the column on the march should remain out until they have been formally relieved by the night outposts.

(11). The pace on the march should be suited to the slowest animals of the convoy, and no straggling of wagons should be allowed. Wagons should march on as broad a front as circumstances permit.

(12). The Convoy Commander should not disperse his escort along the whole line of the convoy, but should keep them in compact bodies where they will be of the most use.

(13). He should avoid unnecessary fighting. The main object is to get the convoy quickly and safely to its destination.

(14). He should never take anything for granted, or neglect any precautions on the assumption that everything is right because no danger is apparent. There is no reason, for instance, that he should omit to reconnoitre dangerous ground because he knows that a force of friendly troops has passed over that ground a couple of hours before.

This sort of slackness as regards security is bad in any case, for a Commander who is content to take things like this on trust is very likely one day to suffer for it, and, even if he does not, he is allowing his men to get into bad and untrustworthy habits in the performance of their field duties. He should always make quite sure for himself that everything is right; it is the only plan.

As a matter of fact, this deplorable fault of taking things for granted, in the manner I have mentioned, was responsible for a great number of "regrettable incidents" during the late war.

Minor Rules for Order and Discipline on the March.

I am afraid that it is necessary after this long list of the more important points to be noted regarding the conduct of a convoy, that I should add some more minor but useful rules, but I shall deal with them as briefly as I can.

(1). The Convoy Commander should make it a standing rule to be on the road at the head of camp a little before the hour appointed for starting, so that he may be readily found by any officers requiring instructions or having any matter to report.

(2). An officer from each unit and section of transport should come to the head of the column on approaching the place appointed for a long halt or the camp, to get orders regarding the position which his own unit will occupy.

(3). No riding on wagons or animals should be allowed, except in case of men who are sick or footsore. These should be furnished with a slip of paper from their own officers, authorizing them to ride on empty wagons.

(4). The slowest section of the convoy and, usually, the pack animals should march at the head. But where there are ammunition wagons, these, as being the most important, should come first, for the head of the convoy is the safest place for them and the road is easier before there has been much traffic over it; there is thus less chance of these wagons breaking down or sticking.

(5). The Convoy Commander should attend to the regulations regarding "Crossing military bridges, fords, drifts, &c.," which are given in Sec. 79 of "*Combined Training, 1903.*" He should also carry out the measures prescribed in Sec. 72 of the same instructions regarding the despatch, somewhat in advance, of an officer to make arrangements for halting and camping and, for what is of much importance, the protection of the water supply until the force arrives.

(6). He should endeavour to have two or three empty wagons to replace breakdowns, and one or two spare teams to help in pulling wagons through bad fords or drifts and up steep inclines or across very heavy ground, or to pull them out of the way if they block the road.

(7). No one should be allowed to leave the line of march without permission or enter houses or gardens, whether the march be through a friendly country or through an enemy's. Where this rule is not enforced looting and loss of discipline are sure to result. Punishment for this offence should be very severe.

(8). All Army Orders regarding payment for supplies from the inhabitants should be scrupulously enforced.

(9). The harsh treatment of animals should be repressed, not only from humane motives but because it spoils the beasts, especially if they are mules.

In the same way the treatment of natives should be firm but proper.

(10). The water carried, whether in carts or on pack animals, should not be touched without express permission. Officers should be enjoined to watch in like manner over the water in the men's water-bottles, as camp may have to be pitched in a place where no water is available.

(11). The custom on the part of officers, which is somewhat common, of interfering with non-commissioned officers and men or civilians on duty with the wagons, or of using rough language to them, should not be allowed. When necessary, the officer in charge of the section of transport should be referred to.

(12). Orderlies should be left where delay is likely to occur through bad drifts, heavy ground, &c., with orders to report quickly when the whole of the transport is across.

(13). Mounted men, except those scouting, should dismount and lead their horses for reasonable periods, so as to save them as much as possible.

(14). Wagons must adhere to their proper place in the order of march. In a badly managed convoy some wagons and even sections of convoy will be continually trying to pass each other, so as to get into camp first. Where this is allowed, blocking of roads and damage to wagons is sure to result.

(15). The commanders of advanced, rear and flanking guards, or of any force detached from the column, should report to the Convoy Commander or his staff officer when they come into camp after being relieved by the outposts, &c. This rule is especially important in the case of the rear-guard, which has to bring in stragglers, lagging animals and wagons.

(16). When the route is not along an established line of communications and there is the least chance of a wrong road being taken by a section of the convoy, it is a good plan for a unit, say a company from the corps forming the rear-guard, to march at the head of the column and drop men where roads diverge. They will be picked up by an officer who will march with the rear of the column expressly to collect them, and they will come on with the rear-guard. This rule is specially useful for night marches, and applies to all columns on the march.

Night Marches.

Night marches are seldom adopted for convoys, except in country where no attack is to be expected, or where it is necessary to avoid great heat during the daytime. It will readily be understood what terrible confusion will arise when an attack is made in the dark. The mounted scouts cannot be out, nor can the covering guards be sufficiently distant from the column to give much notice of an attack.

Oxen, however, move very well at night, and where there is complete security from molestation night marching may be best for them. The animals have then to rest during the day; but if there are many flies, the advantage of marching in the cool hours is discounted by this plague, which does not allow of the animals having proper repose when resting.

Tactical Dispositions on the March.

Coming now to the very important question of the tactical dispositions which should be made to protect a convoy on the march, I would repeat what I have already said—that only exceptionally will a convoy be exposed to possible attacks from an enemy in any strength, when the war is being waged in a civilized country.

General Considerations in European Warfare.

When operating in European countries its front will be covered by the widely extended troops of its own army. The numbers of the enemy which will be able to molest the convoy will therefore, as a rule, be composed of bands of marauders.

But as the advance into an enemy's country progresses, the convoys will have longer distances to cover, and the hostile force which may menace a convoy may be strong enough to seriously imperil its safety. Such was constantly the case in South Africa, when convoys were very frequently attacked by equal or superior forces of Boers, an appreciable proportion of convoys being captured by the enemy during the latter portion of the war.

A mobile enemy may move rapidly round the flank of an advancing army, or, unknown, make a long march from another section of the theatre of war to harass it by striking at its communications, and in either case may come upon a convoy. A notable instance of this is to be found in the early part of the Boer war during Lord Roberts' pursuit of Cronje to Paardeberg. Christian de Wet, hurrying up unexpectedly from the south-east to harass Lord Roberts' rear, struck his main convoy, which was weakly protected, and captured the whole of it, consisting of several hundred wagons and containing the greater part of the supplies of the British force operating against Cronje.

The possibility, in future wars waged in civilized countries, of motor bicycles being used by the enemy to dash rapidly from point to point should also be taken into consideration in dealing with this question.

Necessity for Precaution.

A convoy moving independently in an enemy's country may, therefore, at any moment be liable to attack, and it is incumbent on the commander of its escort to neglect no measure for security which may be dictated by prudence. Constant watchfulness and exactness are indispensable qualifications for every good leader in war; but in the case of a convoy, which can only act on the defensive and which, by reason of its great length in column of route, is everywhere vulnerable, it behoves him to be especially careful in taking every possible precaution.

March not to be Delayed by Small Numbers of Enemy.

He must, however, on the other hand, not be nervous and constantly delaying the march at the first symptom of an enemy in small numbers. His task is to get his convoy on quickly as well as safely. He can attain his object if his dispositions be such that his mounted scouts give him early notice of the presence of an enemy in important numbers, and if, whilst moving through dangerous country, he does not allow his wagons to stretch over too great a length of road whilst on the march.

Moving Caterpillar Fashion.

The latter is an important point when the transport cannot march off the road. One example from my own experience will illustrate what I mean. I had command, half-way through the war, of a convoy of 340 ox and mule wagons, which means a length, in column of route, of about seven miles. I had to pass through country very favourable for a guerilla enemy, and I had no chance of support over a stretch of 70 miles. My escort consisted of 600 infantry, 100 mounted Tasmanians and 2 guns. Deducting the troops of the advanced and rear guards, it will be seen how inadequately the flanks would be guarded on such a long stretch of road with such a relatively small force. The convoy, in consequence, had to move like a caterpillar, the leading wagons parking until the rear wagons were within two to three miles of the head of the column, and then moving on again.

Of course this occasioned some increase of actual time on the march; but it did not make the convoy later in arriving at its final destination; it only meant so much time taken from that which would have been spent in camp. But the delay was not as great as it might seem; by this method both animals and troops were being constantly rested, and the orthodox halts every hour were unnecessary. The work of the infantry off the road on the flanks being very arduous, it gave time for them to get into place, and also for stragglers and lagging wagons to close up. There is no doubt, too, that the country was better reconnoitered in consequence. In moving like this I had as a principle:—When moving in undulating country, which is that generally met with in South Africa, not to allow the *head* of my column to leave the position on which it had halted, until the *tail* of the column had cleared the previous position, so that the lower ground between was covered by fire and the enemy had no opportunity of attacking the flanks without being much exposed to fire from several points. I did 16 to 20 miles a day in this fashion, and was never seriously molested.

A good system, where it is necessary for the convoy not to occupy too great a length of road, and where sections of transport can pass each other, is for one half of the convoy to pass the other when the latter is halted—each half in turn overlapping the other and getting a good long rest. Thus the first half leaving camp would go two miles perhaps, and halt; the second half would then pass through the first, going four miles and halting; in each case the halted portion would tack on to the tail of the portion passing it.

All round Defence necessary.

It is necessary to realize that in any country, and against any enemy, the convoy is as liable to attack from the rear and flank as from the front. It fact, in savage warfare the enemy as a rule prefers not to molest the advanced guard, but to devote his efforts to harassing the flanks and rear of the force. He knows that he can thus worry the convoy as much and run less risks, and that he has a better chance of loot.

The fighting force has accordingly to be disposed so as to afford security from every direction, the strength at different points depending mainly on the configuration of the country.

Advanced Guard.

The duty of the Advanced Guard is, of course, to reconnoitre to the front, and to clear the road of any small parties of the enemy who may oppose its advance.

It should have a proportion of mounted troops to scout to the front. If it can be spared, a mounted force sufficiently strong to turn the flank of small bodies of the enemy opposing the advance is very desirable; but the mounted reserve in the centre should not be too much weakened for this purpose.

The mounted scouts should reconnoitre boldly but carefully to the front, to a distance, usually, of 2 to 3 miles.

There should be some infantry with the Advanced Guard, to support the mounted troops in clearing the road or to escort guns.

If there are guns, they should be with the Advanced Guard when there is a defile in front, or unfavorable country to be passed through, or where opposition may be expected.

The engineers will always march with the head of the column.

Rear Guard.

The special duties of the rear guard are to cover the convoy from the rear and to bring in stragglers, lagging animals and wagons.

It should have some mounted men as scouts to observe in rear, but here infantry with its solid power of resistance is the main arm of defence. The Rear Guard should be fairly strong, for it has a difficult task to perform with a convoy, owing to the frequent delays caused by natural obstacles or by breakdowns on the road; it has to hang on at any cost till the wagons have got clear, and the retirement of the successive units is often a very difficult business.

An ambulance should always accompany the Rear Guard.

Guns will be placed with the Rear Guard when the convoy is moving from difficult to open country, as the enemy is then more likely to attack from the rear.

Flank Guards.

Flank Guards will consist, in ordinary country, of an outer screen of mounted scouts pushed well out, if possible 2 to 3 miles; of mounted bodies, when available, supporting them at a distance of 1,000 to 1,800 yards; and of infantry 800 to 1,000 yards from the convoy.

The duty of the scouts is to observe; of the mounted bodies to chase away small parties of the enemy; and of the infantry to afford support to the mounted troops and to repel a more serious attack.

When, as will often happen, there are not sufficient mounted troops with the escort to provide supporting mounted bodies, the work of the mounted scouts becomes of double importance as, with an insufficiency of mounted troops, it is of the utmost moment to the escort Commander that he should have the earliest possible notice of danger, so as to be able to reinforce the threatened point in time with infantry.

The mounted scouts are, in any case, the main safeguard of the convoy, for, in case of serious attack, preparation for defence, with a long line of transport, must of course be a slow process, and it is essential that the Commander should have timely information of any serious menace by the enemy.

Reserve.

There must always be a reserve somewhere near the centre of the column. However weak the escort may be, and however desirable it may be to have strong advanced guards, etc., a Reserve proportionate to the strength of the escort should on no account be omitted. Roughly speaking, it would be formed of a quarter to a half of the fighting force, the proportion diminishing as the total strength decreases.

It is most desirable, when possible, to have available with the Reserve a good mounted force which can be sent rapidly to any threatened point. There should be some infantry also, ready to support the weak and extended flanks, or to act as escort to the guns, which should march here when they are not specially required in front or rear.

Guns.

It may sometimes be advisable, when a defile or particularly dangerous bit of ground has to be passed through, that the guns should be posted in a commanding position to cover with their fire the passage of the column over this special tract of ground. They would then join on to the rear guard, where they might be wanted to cover the rear guard on its retirement from the same difficult country ground.

Infantry Escort for Guns.

Guns should never, on the march, be left without an escort. The escort will be generally infantry, and should, if possible, consist of at least a company. As the infantry pace is too slow for horses and only fatigues them, it may often be desirable, where the road allows, for the guns to start a little behind the infantry, catch them up and halt again.

As regards keeping the guns together, I know that artillery officers object to guns being used singly, but if there are only two guns with the escort, as will usually be the case with ordinary convoys, it may be necessary to use them so. I think, myself, that there are occasions when they would be used singly to advantage.

Mounted Troops.

Mounted troops should move in more or less extended formation when off the road, the extension being greatest with the scouts.

Scouts are best used in pairs, riding some yards apart. If an enemy is observed, one can ride back with the information whilst the other continues observing. The distance between them depends on the numbers available and on the open or close nature of the country through which they have to reconnoitre. Pairs of scouts may be as near as 20 yards in close country, and as distant as half-a-mile on very open ground with no nullahs or dongas and very low vegetation.

Mounted men not actually scouting should dismount and lead their horses as much as possible.

Infantry.

The infantry with the advanced guard should always have a proportion of men extended across the country on each side of the route, with the special object of "making good" ground which the mounted troops have not been able to search properly. The remainder should be on the road in close formation, unless there is good marching ground by the side of it, when they can move on a broad front, if considered desirable, so to avoid the dust or lessen the heat.

With the rear guard, there should be a line of skirmishers supporting the mounted scouts and covering the retirement; this line will itself be supported by a portion of the remaining infantry moving on a broad front.

The balance of the infantry may move on the road and act as a local reserve or as escort for the guns, if these are in this part of the column.

The infantry of the flanking guards should always have their own infantry scouts on the outer flank, so as not to be dependent on the mounted troops for safety from surprise; these may have been unexpectedly drawn away for some special purpose and, in any case, they are a long way out and not always visible, whilst the ground between the two bodies may be broken or covered with patches of vegetation which might conceal an enemy. The infantry scouts, in ordinary country, would be 200 to 400 yards from their supports which, in their turn, would be about 800 to 1,000 yards from the column, the supports moving when possible on commanding ground.

The best formation for the supports is in Indian file, moving parallel with the route, the men being usually about 5 paces one behind the other. In this formation they can at once form front to the outer flank in proper line.

Distribution of Troops by Arms.

No fixed rules can be laid down as to the actual proportion of troops of the several arms which should be allotted for the defence of the different parts of the column.

If the country in front is such as to suggest the probability of opposition, the advanced guard should be proportionately stronger.

Again, if the column is leaving dangerous ground, the rear guard should be strengthened, the allotment of the guns being in accordance with the same idea.

To give a general idea of the distribution of troops in fairly open country with an average sized convoy of about 150 wagons, such as usually moved about South Africa with an escort consisting of half a battalion, 100 mounted men and 2 guns or a pom-pom, I would suggest the following allotment :—

Advanced Guard.—One company of infantry, 30 mounted men and the pom-pom.

Rear Guard.—One company of infantry and 10 mounted men.

Flank Guards.—Half company of infantry and 15 mounted men to each flank.

Reserve.—One company of infantry and 30 mounted men, with, as a rule, the guns.

Convoys in Mountainous Country.

Convoys will not, as a rule, move independently through a mountainous district in an enemy's country. They would either march immediately in rear of the expedition, or else they would find the roads picqueted for them by troops from the fighting force.

It sometimes happens, however, that a convoy has to move independently through mountainous country. In that case the escort should be a strong one, and it should be composed almost entirely of infantry, with perhaps a couple of guns, probably mountain guns on mules—more would be of little use, and would only add to the length of the column.

Owing to the nature of the country and the impossibility of having mounted scouts out, the Commander of the escort must take every possible precaution against sudden surprise.

His march will generally be a slow and anxious affair, for his flanking parties will have to seize and picquet the heights commanding the road over which the convoy must travel; otherwise disaster is almost certain if the enemy is enterprising and determined.

This picqueting system is that in which groups of men occupy the heights commanding the road on each side, whilst the column passes between them. Where the country is hilly rather than mountainous, each group remains in position until it is relieved by the group following it, when it moves on to the next commanding point, where it relieves the group that has immediately preceded it, and so on in constant succession.

But where the mountains commanding the road are of great height, this method is not feasible, as the labour of moving along the heights parallel to the road is too great. Each height has, in that case, to be occupied by a party detached from the head of the column, and this party remains in position until the column has passed, when it comes down and joins the rear guard.

It may, however, sometimes happen that mountains commanding the route are of such height or inaccessibility that it would involve too much effort and time for a party to reach the summit, or it may be that the weakness of the fighting force will not allow of a party being sent which would be strong enough to safely act independently. In this case, if a circuit cannot be made, the only plan is for the column to move along that side of the valley which will offer the greatest immunity from fire from the unoccupied height; and for a detachment of infantry, with guns if available, to hold the most advantageous position for maintaining an effective fire, if necessary, on the summit of the mountain which menaces the route, until the column has passed the dangerous point.

In such a country it is best to establish a line of communications in which all important points are picqueted daily by troops specially detailed for this purpose from fortified camps (as was done in Tirah) or are defended by permanent posts or by a combination of daily picquets and permanent posts, as local circumstances and convenience may dictate. Where posts are occupied daily it is essential that full precautions should always be taken in advancing to them. Men are apt to be slack in this respect after many days of immunity from attack, but an enemy such as the Afridis will notice this slackness, and the picquet advancing to its post may be ambushed and shot down at close quarters. A very unfortunate incident, due to the want of precautions in this respect, occurred in Tirah; a picquet advancing up a hill to its post was fired upon by the enemy as it was approaching the summit in careless fashion and without scouts, and every man was shot down.

Convoys in Savage Warfare.

In dense jungles, which often cover the whole surface of the land, convoys will almost always accompany the fighting force; but, in any case, they will, if threatened, form a square, which is the only safe formation for efficient protection in event of serious attack.

This method was invariably adopted by the French in Dahomey and by the British in Ashanti, and always proved satisfactory. In expeditions in these regions, the column, when on the march, was covered by flanking parties and by a rear guard. It moved, in fact, in the form of an extended elastic square. Native scouts were far out on all sides.

In jungle warfare it is most important to constantly preserve touch, and great care must be taken that no extensive gaps are left through which the enemy might penetrate. Constant halts will generally be necessary for this purpose.

An excellent way of marching is in échelon formation on each flank, the convoy being in the centre. In this way a heavy fire to the front can be secured in a moment, and if a rush is anticipated the troops can readily get into square formation if required. This échelon formation gives more breathing space, and is elastic for dodging minor obstacles.

At Suakin in 1885, convoys were sent out under an escort of troops which formed a close square or oblong round the transport, the whole force advancing in this formation, but with many halts to ensure the proper formation being kept.

The difficulty in these close square formations is to prevent the occurrence of gaps through which the enemy can rush. Such gaps are easily caused by the pressure of animals causing one of the sides or corners to bulge out, and every care should be taken to avoid this. When square formation is adopted it is almost better to have no infantry scouts out, as the force is then in constant readiness to fight whereas scouts running in obstruct the fire of the square.

It has however been usual, in the Sudan, to keep the mounted troops outside and quite independent of the square. They can thus reconnoitre more effectively, and mounted troops who can gallop clear away seem under the circumstances to be better adapted for this purpose than infantry skirmishers who have to get back into the square if the enemy closes. Of course if the mounted force is very weak the case is different. The Russians in Central Asia, when adopting the square formation, also generally kept their mounted men outside the square. Mounted troops acting thus outside the square should not be too far off to render assistance; but they should not, on the other hand, be so near as to mask effective fire from the square.

It is unfortunate when circumstances oblige large convoys to march in square, no matter how strong the force may be that is protecting them; for progress is slow, and the animals easily get into disorder. But when there is a probability of very sudden attack it is the only possible order of march, though the échelon formation which I have just mentioned is very often desirable.

Other great objections to square formation are the limited development of fire and the fact that it offers a particularly good target for the enemy.

It should be noted that it seems advisable not to put single guns or maxims at the corners of squares; if they are to be worked singly they are best in the centres of the sides. When in pairs they are often put at the corners, but experience seems to show that the corners are not in any case the best positions for them. It may often, however, be very desirable to place the guns outside the square, the men of the detachment running into the square in case of a close rush; the guns have thus a better and wider field of fire.

Conclusion.

In conclusion I would again impress on you, should you ever have the rather ungrateful task of commanding a convoy, the absolute necessity of taking no chances.

In guerilla warfare the policy of the enemy is to watch without being seen. If you are careful you may never know how near you were to being attacked. The enemy is much less likely to attack if he sees that all proper measures of precaution have been taken, and if he does come on he is much less likely to hurt you if you are forewarned.

In addition, the knowledge that prudence and foresight are governing the conduct of the column gives confidence to the troops, and helps to maintain order and discipline.

Never take anything for granted, but make sure for yourself, and be ever vigilant.

It may be pardonable to be defeated, but there is no excuse for being surprised!

PAPER II.

THE ANGLO-LIBERIAN BOUNDARY COMMISSION, 1903.

BY

LIEUT. E. W. COX, R.E.

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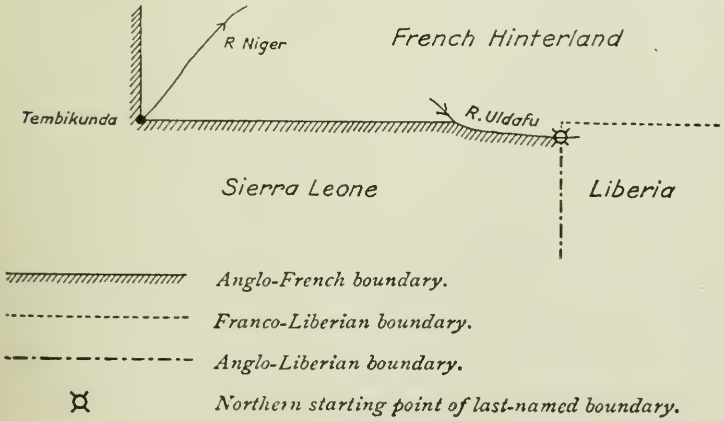
THE ANGLO-LIBERIAN BOUNDARY COMMISSION, 1903.

PART I.

WORK OF COMMISSION.

Description of Boundary.

The boundary to be delimited was described as starting from the intersection of the river Uldafu with the 13th meridian West of Paris, and following this meridian Southwards to its intersection with the river Mannah, from which point to the coast the left bank of the river Mannah at low water formed the boundary.



The northern starting point was also the end of the Anglo-French boundary of Sierra Leone and the beginning of the Franco-Liberian boundary.

The position of this starting point was unknown, but the source of the river Niger, which rose near the village of Tembikunda, had been determined, both for latitude and longitude, by Lieut.-Col. S. C. N. Grant, C.M.G., R.E., in connection with the Anglo-French Boundary Commission of 1895–96. These data were given to both Commissioners as the basis of their work.

Thanks to this initial longitude there was no necessity to take out any instrument for an absolute determination of longitude. It was only necessary, before actually starting work on the boundary, to fix, from the source of the Niger, the intersection of the river Uldafu and the 13th meridian West of Paris.

Arrival at Tembikunda.

The commission left England on December 20th 1902, and arrived at Freetown, Sierra Leone, on January 1st 1903.

The working season on the West Coast of Africa varies slightly every year. The first rain-storm on the Liberian frontier in 1903 was on February 10th; the next two were on March 8th and 12th. The tornado season began on March 23rd and lasted till April 24th, with two intervals from April 1st to 7th and April 12th to 24th. The rains began in earnest on April 24th.

To have taken full advantage of the dry season the Commission should have started at least three months earlier. Work on the boundary could certainly have been commenced at the beginning of November, but the Commission did not reach Tembikunda till January 24th. This late start however was unavoidable.

The Commission left Freetown by railway on January 8th, and reached Bo, the rail-head, on the evening of the same day. At Bo all loads were reduced to a maximum weight of 56 pounds; and the 300 odd carriers were organised into gangs of about 25 men each, under headmen, to facilitate quick pitching and striking of camps.

The Commission left Bo on January 12th and, with the exception of one day's halt to replace some 30 carriers who had bolted, marched through to Tembikunda, which was reached on January 24th. The length of the march was about 165 miles, so that 14 miles may be taken as an average day's march for a Commission in one party at the beginning of a season's work.

The village of Tembikunda had disappeared, and the neighbouring village of Konkonnante was deserted ; but there was no difficulty in identifying the pool at the source of the Niger which had been carefully described in the 1895–96 *procès verbal.* Two bottles were found, which had been left by French commissions in 1882 and 1885 and which contained short accounts of their work ; the natives had made no attempt to remove them, as they considered the pool to be the abode of a devil.

The party available for survey work consisted of :—

Capt. H. D. Pearson, R.E., the British Commissioner,

Lieut. E. W. Cox, R.E., Assistant Commissioner,

Sergt. A. R. Briscoe, R.E., and

Lce.-Cpl. C. H. Dillon, R.E.

Lieut. R. A. Cockburn, West African Frontier Force, who commanded the escort, made some excellent road sketches.

Locating the Starting Point.

As the boundary followed a meridian for the first 100 odd miles, it was necessary to determine the longitude of the starting point as accurately as possible. Triangulation was found to be possible, and so was of course adopted.

Base Line.

A site for the base was selected, and signals were erected at each end and on suitable trig. points. While the two theodolites were used for observing to and from these different points, Lieut. Cockburn and the two N.C.O.'s spent four days in clearing the base and improving it for measurement. Two trestle bridges were built over swamps, and cuttings and embankments made wherever it was possible to preserve a uniform slope by such means.

The extremely short length of the base, 3,073 feet, was due to the necessity of having well-conditioned triangles to start with, the broken nature of the ground and the haze from bush-fires rendering long rays impossible. The base was measured four times, with a mean P.E. of 1 in 84,000.

The P.E.'s of observations or measurements, which are given in this paper, are mentioned purely as a matter of interest and comparison, and with no idea of giving a true estimate of accuracy. So many sources of error are unavoidably neglected in obtaining the P.E. of any set of observations or measurements that the result can only be relative.

Before the true length of the base could be finally determined it was necessary to obtain its height above M.S.L. Four barometers, which had been read at the coast, gave a mean height differing from a hypsometer height by 180 feet. To decide how these heights should be weighted, the difference in height between the bottom and top of Mt. Konkonnante, the highest trig. point in the neighbourhood, was obtained by barometers, hypsometer and trig. work. The barometers were found to be much more reliable than the hypsometer, and so the barometer and hypsometer heights of the base were weighted as 2 to 1.

No satisfactory record can be given of the change in the barometers' index errors during the work on the boundary. The only barometer which was available was read again at Freetown at the end of seven months, and showed a change in index error of + ·183 inches. This was in no way due to the different seasons at which the readings were taken.

Col. Grant's datum point was connected with the triangulation and gave the initial latitude and longitude. Ten values were obtained for the initial azimuth, with a mean P.E. of 1·54″.

Both sun and stars were observed, as even at that time cloudy nights were so frequent that it was impossible to depend on star observations alone. There seems to be a certain prejudice against using sun observations for time or azimuth. After a little practice an error less than one-third of a second was always obtained in sun observations for time, and generally an error of less than 10″ in sun observations for azimuth.

Triangulation to Starting Point.

The triangulation was then carried East to the meridian, embracing an area of about 50 sq. miles.

On hills covered with long jungle grass, rough wooden signals, with cross-vanes and a white streamer, were erected; on tree-covered hills, either one tree only was left standing or one was rendered easily recognisable by a piece of white cloth. The importance of white cloth in any survey work which involves the observation of signals at a distance cannot be overestimated; its use often saved us the loss of a day in the constant haze which prevailed in February and the early part of March.

Two values were obtained for each side in the triangulation, and the average distance between two such values was 6 inches. The average length of each side was 2 miles. Two values were also obtained for each height, and the average difference between two of these was 9 inches.

Four weeks passed between the day on which the site for the base was selected and the time when all computations necessary for fixing the meridian beacon were completed. But more triangles than necessary were observed, as the Commissioners acting for Liberia had not arrived. Three weeks from the date of reaching the starting point should have been sufficient to get well away on the trig. work, keeping all computations up to date.

SOUTHWARDS ON THE 13TH MERIDIAN.

The triangulation was continued for about 8 miles down the boundary, but was then found to be infeasible. The impossibility of getting an average length of over 2½ miles for the sides of triangles made triangulation very laborious and very slow; the country itself began to lose its hilly character and to become an undulating expanse of bush; and, finally, the necessity for the two Commissioners meeting every day, to compare work and superintend the erection of beacons, induced Capt. Pearson to adopt a subtense traverse.

Subtense Traverse.

Corpl. Dillon, with a small clearing party was sent on ahead to erect signals. It was soon found that the subtended angle should be 8 to 12 minutes to give the best chance of good results. So when the selected forward point was reached the direct distance to the back point was estimated, and the length of the subtense base determined in the proportion of a 30-foot base for a 10,000-foot ray. A centre post was then erected on which forward and backward bearings could be taken. A line through this, at right angles to the ray, was then carefully laid out by compass, tape, or any available means, and the subtense poles erected equidistant from the centre pole.

These poles were thin trees, 2 to 3 inches in diameter, stripped of bark and blackened for 3 feet above the ground. Large bundles of bush-grass and, for long rays, wicker cones (made by the carriers on the spot) were attached to the tops of the poles to make them conspicuous. The poles were also guyed with bush-rope to ensure their remaining vertical.

A short way behind each of the subtense poles was stretched a piece of white cloth, or towel, so that the observer had to intersect a black mark on a white background; this combination was found to be far preferable to any other. The ground all round each pole was then cleared of all obstructions right down to the ground level, as it was very important for the observer to obtain the exact intersection of the poles with the ground; in the few cases where the ground or undergrowth rendered this absolutely impossible the poles were carefully plumbed.

Lastly the distance between the two subtense poles was measured with a tape. It was found impossible to rely upon a native to hold the end of the tape in the centre of the pole, so a nail was driven into one pole and the ring on the tape end put over the nail. The N.C.O. engaged on this work was kept constantly informed how much he was off the meridian, and was thus able to select his own forward points by his compass, without reference to the observer behind.

The observer, on arriving at a station, at once measured the distance between the subtense poles which he found there. Next he took 3 sets of 10 readings (as a general rule) on the back and forward subtense bases, and observed the angle between the back and forward centre poles. He then altered the subtense poles, placing them at right angles to the new ray, measured the distance between them, and went on to the next station.

The number of subtense readings varied with the conditions under which they were observed. Three sets of 10 was the minimum; but if haze, shimmer or dull light made the readings difficult, more were taken, as many as 6 sets of 10 being sometimes recorded. The best times of day for observing were before 8 a.m. (if the mist would allow) and after 4 p.m.

The advantages of this subtense method were great. The observer was never far from the meridian, and a quick calculation at each station enabled him to plot his position on his plane-table. During his march to the next station he plotted the path as he went; so that when he encountered any roads, streams or prominent ranges, which were likely to cross the boundary, he was able to traverse down them—either on his plane-table, or with the compass and the latitude and departure table in Chambers' Logarithms—until he came to the boundary.

The rays were generally 2 to 3 miles long, the actual average length of all being 2¾ miles; the longest was 11½ miles. Two rays were usually observed in one day. After a little practice a discrepancy of about 1 in 400 was obtained between the two values for each ray; the actual average discrepancy in all the rays worked out to 1 in 1,300, but this exceedingly small average was due to one or two flukes in some very long rays.

Rounds of angles to distant peaks, or other prominent objects, were observed at all convenient stations; and a short triangulation, based on a carefully observed ray which had a discrepancy of 1 in 1,100, was carried some 6 miles eastward from the traverse to fix the position of Kamiendo, an important outpost town in Liberia.

Observed Latitude Stations.

This traverse, which was carried down to the point where the river Mannah became the boundary, was about 100 miles along the meridian. There were accordingly 4 observed latitude stations, and the differences between the traverse and astronomical amplitudes were 1″, 2¼″, 3¾″ and 1″.

At each observed latitude station a mean was taken between the traverse and observed latitudes, and the traverse longitude was corrected by this. The longitude of the final point of the traverse differed from the value obtained by the Commissioners for Liberia by some 20 feet. The latitude, longitude and reverse azimuth at each station of the traverse were computed from the Indian "*Survey Tables.*"

During the traverse Lieut. Cox and Sergt. Briscoe mapped as much of the country as possible on the East and West sides of the boundary respectively, using plane-table or compass according to the country. Lieut. Cox in addition returned to the main camp to assist in astronomical observations.

The traverse was started on March 11th and was finished on May 29th. Deducting a week for the Kamiendo triangulation, a rate of 1½ miles a day was obtained. This rate may seem very slow to those accustomed to work in open country; but it must be remembered that a very great amount of clearing was found necessary and that beacons had to be erected as the Commission proceeded. The last 30 miles of the traverse lay through the so-called impenetrable forest, which stretches south from Bariwalla to the river Mannah; a road was cut through this forest by compass bearings, and 5 stations were erected on prominent hills. Anybody who knows what a tropical forest is like will realise the clearing that had to be done on each hill before it was possible to observe both forward and back. As a matter of interest it may be mentioned that the average daily march through this forest was 2½ miles. The only work done during the day was to cut a path wide and high enough for carriers with loads to pass along.

DOWN THE MANNAH R.

Chain and Compass Traverse.

Owing to rice troubles the Commission was unable to start down the river Mannah till June 14th. The rains had been in progress since April 24th, all the rivers and creeks were very full, and the country was flat and covered with forest, So Capt. Pearson decided to carry a chain and compass traverse to the coast; a river traverse was impossible as the river did not become navigable till 30 miles from the coast.

The chain, of 300-foot steel tape pattern, was dragged along the bush-path, and bearings taken on sound at every 500 yards. The average rate was 14 miles a day for 8 days, the longest march being 21 miles in one day.

Observations for time and latitude were taken every night, when clouds permitted. The observed latitude at each halting place was assumed to be correct, and a mean traverse longitude was obtained from this by assuming (i.) the bearings correct (ii.) the chaining correct.

Another longitude for each observed latitude station was obtained from 3 chronometer watches. These had been "exercised" for a week before starting, and their marching rates obtained. They were again "exercised" for a week at the coast and a second set of rates obtained. Their mean marching rates were used to obtain the chronometer longitude of each station.

These two longitudes, obtained from the traverse and the watches, were weighted inversely as the squares of their probable errors, and so gave a final longitude for each station.

During the 8 days' march the rate of one chronometer watch changed from a gaining daily rate of ·7 second to a gaining daily rate of 7 seconds. It would seem useless to attempt to carry longitude by chronometer watches only, unless with at least 8 of them.

Capt. Pearson had hoped to obtain the longitude of the mouth of the river Mannah from Freetown, by carrying chronometers to Freetown and back. Owing to the lateness of the season, however, the Admiralty were unable to place a boat at his disposal.

The longitude of the final point on the coast differed from that shown on existing maps by 4 miles. Before the Commission's map could be fitted into the 1 in 1,000,000 map of Liberia, a P.E. for the final longitude was asked for; this was found to be 2 miles, and lay entirely in the chain and compass traverse, giving it an error of 1 in 55.

ASTRONOMICAL OBSERVATIONS.

The instrument used for all astronomical observations was a 5-inch micrometer theodolite. The best set of time observations by the sun had a mean P.E. of ·066 seconds; the best of those by stars had a mean P.E. of ·051 seconds. As a matter of interest two or three time observations, which consisted of only 1 pair of observations on 1 star, were worked out, and in no case did the result differ by more than ·75 seconds from the mean of a complete set of time observations on the same night.

With regard to latitude observations it was found that much better results were obtained by taking a large number of short observations than a small number of long ones. Good results could not be obtained from stars with a zenith distance greater than 55°. In the computations each pair of left and right face observations was worked out separately, to obtain an idea of the accuracy of the observer.

The smallest range (between the lowest and the highest pair in one set of observations on one star) was 3·205″, the greatest was 23·905″, and the average of all was 12″. The average number of pairs of observations on one star was 6.

The P.E. of the best latitude observation was ·4″, and that of the worst 2·1″. One or two latitude observations, consisting of only 2 pairs, were worked out, and gave a result differing by less than 5″ from the mean of a complete set.

For latitude computations Bessel's *Refraction Table* was always used. But for high altitudes log B in Table D is not given. As many latitude observations were taken at altitudes at which the barometer read less than 27·5 inches, a constant log was worked out, by which log B could always be obtained ; the formula was

$$\log B = \log b + K$$

where b is the barometer reading in inches, and K is the constant log $\bar{1}\cdot4712443$.

PART II.

NOTES ON EQUIPMENT.

INSTRUMENTS AND TOOLS.

Instruments. The following Instruments were taken :—

FROM TROUGHTON AND SIMMS.

Two 5-inch micrometer theodolites with all fittings	about £95.

FROM ELLIOTT BROTHERS.

Four 8-inch chemical thermometers ...	7s. 6d. each.
Three 2½-inch aneroids, reading to 6,000 feet	£3 7s. 6d. each.
Two 100-foot ½-inch steel tapes	£2 7s. 6d. each.
Three 3½-inch prismatic compasses on tripods	£5 15s. 6d. each.
One hypsometer	£5 15s. 6d.
Two Abney levels in sling cases	£2 5s. each.
Two rolls of drawing instruments ...	£3 7s. 6d. each.
Two sets of four 12-inch boxwood scales, divided to the scale of the survey ...	14s. each.
One 36-inch brass diagonal scale, 1 in 250,000	£4 4s.
One 6-inch circular brass protractor ...	£1 12s. 6d.
One beam compass	£1 7s. 6d.
240-foot log line	£1 8s.

Elliott's net bill was £52 10s.

FROM THE ADMIRALTY.

Three M.T. chronometer watches.

FROM THE ARMY ORDNANCE, WOOLWICH.

Two measuring chains, 100-foot.
Two magnetic compasses, Mark IV.
One Indian clinometer.
Two 6-inch ivory protractors.
One set of mathematical boxwood scales.
Two 5-inch heliographs, Mark III., with stands.
Two heliostats.
One signalling telescope, Mark II.

FROM S.M.E., CHATHAM.

Four 24-inch × 18-inch plane tables, provisional pattern, with sight-rules.
Four trough compasses.

FROM EDW. STANFORD.

Survey books, cost about £6 10s.

FROM WATERLOW & SONS.

Stationery, etc., cost about £21 10s.

FROM THE ARMY AND NAVY STORES.

Three electric lamps with refills,	£2 7s. 6d.
Three bicycle lamps with oil,	17s. 9d.
Two rolls of carpentering tools,	£2 10s.

The theodolites, which were made in 10 days, were quite satisfactory on the whole. The results proved that a 5-inch micrometer theodolite is quite large enough for general work. The only fault that could be found with them was that the telescopes were not quite powerful enough for trig. work.

The steel tapes and the chains were not satisfactory. It would be better to get, as standards, one or two 100-foot steel tapes, with spring balances, winding on to wheels; and for ordinary work some longer ones, 300 or 400 feet (the American tapes 300-foot by $\frac{1}{8}$-inch, lent by the Commissioners for Liberia, were excellent).

The prismatic compasses on tripods were good, and gave accurate results in the bush-path sketching in flat country. They had to be constantly tested once the tornado season had begun, as the pivots were liable to rust in spite of all precautions.

The plane-tables were sent out to be tested under working conditions, and were a failure. They have since been condemned since then, and a new pattern is now under experiment, so the causes of their failure need not be recorded.

The electric refills went wrong. If electric lamps are taken, and communication with the coast is easy, refills should be sent out every 3 months at least.

Tools.

The following Tools were taken :—

FROM THE ARMY ORDNANCE, WOOLWICH.

Six felling axes, with spare helves.
Two crowbars.
28 lbs. of 22 B.W.G. wire.
Two pairs of pliers.
25 fathoms of 3-inch rope.
Six pickaxes, and six shovels.
20 buckets.

FROM SIERRA LEONE.

Two hundred matchets.
Six felling axes.

All the tools were of the greatest use. The rope was invaluable for crossing rivers in flood.

The clearing tools should always be supplemented by native axes, as the natives work better with their own pattern than with strange ones.

The 200 matchets lasted both Commissions, about 500 carriers in all, just the 6 months.

Plenty of nails should always be taken.

Camp Equipment.

Camp Equipment.

The following camp equipment was taken :—

FROM SILVER AND EDGINGTON.

For Messing and Computing.

Two No. 2 Willesden canvas double-roof ridge tents	£11 12s. 6d. each.
Four Uganda tables	£1 2s. 6d. each.
Two Lord's lamps	35s. each.
Three canteens (for 8 people in all) ...	£6 7s. 6d.

For each member of the Commission—

One No. 4 tent	£7 15s.
One camp bedstead, etc.	£2 17s. 6d.
One camp washing set	15s. 6d,
One Cyprus table	12s. 6d.
One deck and one Wycombe chair ...	£1 3s. 6d.
One mosquito curtain	15s.
One lantern	11s.

The No. 4 tents were a little small. The No. 2 would be a more comfortable size, and could be carried by the same number of men.

There is not much scope for choice in camp equipment. But it should be remembered that bedsteads, tables, chairs, etc., will have to be put together by natives, and should therefore be as simple and with as few separate parts as possible.

The Lord lamps were excellent.

FOOD.

Food.

The *amount* of food to be taken depends of course upon the resources in the country itself, and the *choice* of it on individual taste.

It is recommended that special brands of tinned meat, jam, etc., should be named in the order, instead of leaving these to the discretion of the catering firm. The system of packing in which each ordinary box is complete in itself is preferable to the wholesale system.

It is very difficult, without previous experience, to estimate the amount of milk that should be taken. A fair ration is $\frac{1}{4}$ lb. of Swiss milk per man per day.

Our food and drink for 6 men for 6 months cost about £260.

KIT.

Kit.

Pith helmets of the Cawnpur Tent Club pattern are excellent against the sun, but are of course useless in the rains. The "Kitchener" helmet is very good against rain and sun, but is heavier than the pith ones. Felt hats are very useful for evening wear.

Soft chamois-leather Wellingtons are invaluable as mosquito boots.

Putties are the only leg-covering that will keep out ants.

Shirts and pyjamas should always be of flannel.

Coats are never worn in the daytime on the march. The best material for coats and breeches is light khaki-cloth, which is invisible in the bush and so very suitable for shooting.

PAPER III.

FORTIFICATION IN ITS TACTICAL APPLICATION.

BY

CAPTAIN H. F. THUILLIER, R.E.

(*Lecture delivered at the School of Military Engineering, Chatham, on* 10*th March*, 1904).

FORTIFICATION IN ITS TACTICAL APPLICATION.

"FORTIFICATION is a difficult science, in which the least mistakes may have a great influence upon the success of a campaign and the fate of a nation."

"Field Fortifications are always useful, never hurtful when they are rightly understood."

In these words the greatest master of modern war, the great Napoleon, has left on record his opinion of the value of fortification, and of the necessity of understanding its capabilities, its limitations and the method of employing it. History affords many instances of the serious injury which the ill-judged employment of fortification may inflict on a commander who is ignorant of these principles.

There are many occasions where the assistance of fortification is most useful, in fact absolutely essential, to secure certain strategic ends; others where it could effect nothing, and where its use might even be detrimental. It is from the strategic situation that one should judge as to the desirability or otherwise of having resort to fortification in any particular case, and from the tactical conditions as to the method in which to apply it.

This statement applies in an equal degree to permanent fortification and to field defences. Though the nature of the works would differ considerably in these two cases, yet in both of them this is governed by the strategic and tactical conditions, and so also is the method of employing them. The length of time for which they are intended to fulfil their object of detaining the enemy with a small force—which in the case of permanent defences may be for months, and in field defences only for days, or even hours—is merely one of the strategic conditions which have to be considered.

STRATEGIC LIMITATIONS OF FORTIFICATION.

Since the South African War it is probable that most people have sufficiently realized the capabilities of fortification in defensive warfare. We now know that by its means a few men with modern weapons can keep off a greatly superior force for a long time, and that by the improvements in modern armaments the resisting power of even the roughest defences has been greatly increased. So great an impression has been made on us by the revelation which the war gave of the tactical strength of fortification in passive defence that there may be some danger of our overlooking its strategic limitations. Yet a recollection of its limitations is of vital importance to prevent its improper use.

It should be remembered that troops behind fortifications can themselves achieve *nothing* towards defeating the enemy; all they can do is to enable other portions of their own side to defeat him by means of offensive operations. For instance, a portion of a force may take up a defensive position to enable the remainder to carry out a turning movement; a portion may move rapidly ahead to seize an important position and hold it till the remainder arrive; again, a portion may hold a position to permit of the retreat of the remainder, as in rear-guards, or at a distance from the main body to give the latter time to deploy for battle, as in outposts and advanced guards. In all these and many cognate cases fortification is of the utmost value.

In a similar manner permanent fortresses are valuable for the purpose of guarding a base of supplies or a line of communications, for they enable this to be done with a small number of troops, and thus set free for field operations a larger proportion of the force than would be advisable where they did not exist. Also, a fortress, large or small, may secure at the beginning of a campaign an important strategic point, such as a railway junction, a bridge or a mountain pass, until the main body can be mobilized and brought to the spot. But fortresses, however strong, cannot take the place of a field army; even a line of them cannot defend a tract of country, except for a limited time, if they can be surrounded and their communications cut. All they can do is to create time for the field armies to come upon the scene and defeat the adversary.

Thus the commander of an independent force does wrong if he takes up a fortified position and allows himself to be held to it and surrounded, unless the strategic situation clearly demands such a course for some definite end. In such a case the defending force can accomplish nothing effectual until another force comes to relieve it, and if no such force is available it is inevitably lost sooner or later. Even in defensive warfare and against superior forces fortifications are often a snare and delusion.

There are many examples in history which prove this. It will suffice to refer to a couple of the best known and most striking cases.

Ulm, 1805.

The first is that of Ulm in 1805. The fortress of Ulm is situated at the confluence of the Iller with the Danube, on the western frontier of Bavaria. In 1800 it had been the scene of a successful defence, whereby an Austrian army, under Kray, had barred the advance of a superior French force under Moreau for a period of six weeks. In 1805 the Austrian and Russian Emperors formed an alliance against the French. At the outbreak of the war the Russian armies were still in their own country; the French Grand Army under Napoleon was on the shores of the English Channel. The Austrians, without waiting for the Russians, marched into Bavaria and took up a defensive position on the line of the Iller, with their right flank at Ulm. It was their intention here to oppose the advance of the French until the Russians arrived and joined forces. But the Russians were much too far away to render their arrival within a reasonable time possible. Napoleon moved his army corps across France and into Germany with the utmost celerity and secrecy. Making a wide turning movement round the right of the Austrian position, they appeared in its rear, and cut off its defenders from their communications with Austria and with the Russians. The Austrian commander concentrated the bulk of his forces at Ulm, still hoping to be able to hold out at that place; but Napoleon, who had an immense numerical superiority, drew closer the net round the defenders, barred every avenue of escape and vigorously pressed them on all sides. After a vain effort to break out, the entire Austrian army laid down its arms.

It appears that the Austrian commander, Mack, a man of no military capacity, was blinded by his knowledge of the existence of this fortress and of its successful defence on a former occasion; and was thus led to place his army in a very advanced position, far from the support of his allies, and subject it to the risk of being surrounded and invested by a greatly superior force. Such a proceeding under any circumstances could only be classed as a gross strategic blunder, which, when opposed to a commander of the genius of Napoleon, was bound to be attended by fatal results.

Metz, 1870. The second case is that of Metz in 1870, which is probably already familiar to everyone. Metz was at that time the strongest and most modern fortress in France. It was surrounded by detached forts and was occupied by a garrison of 30,000 men, for which number it was supplied with provisions to resist a siege. After the defeat of Gravelotte, Marshal Bazaine, with his army of 150,000, retired into Metz, and was immediately invested there by the Germans. There was no other French force in a position to come to his assistance. The remainder of the army under McMahon was in the act of retirement towards Paris; but, in consequence of orders from the Government, this Marshal turned eastward with a view to extricating Bazaine. But other German corps were moved so as to head him off, and then ensued that series of movements which ended so fatally on the 2nd September at Sedan. Bazaine in the meanwhile made a great but unsuccessful effort on the 31st August and 1st September to break out *viâ* Noisseville and join McMahon, and also several minor sorties later. It did not take long for the 150,000 men of his field army to consume the provisions intended for the garrison of 30,000, and when they were exhausted the Marshal with his whole army capitulated. It is not necessary here to discuss the questions which have been raised as to whether ulterior political motives, or personal ambitions, had anything to do with Bazaine's action in retiring into Metz and his capitulation there. From the military and strategic point of view it is clearly shewn that a field army which allows itself to be shut up in a fortress without hope of early relief commits an act of suicide.

Offensive Strategy Essential for Victory.

Virginia Campaign, 1862–4. A defensive campaign therefore can in no circumstances be carried out by the passive defence of fortresses, however strong. To secure victory blows must be struck, and this is best accomplished by the defenders manœuvring so as to concentrate the whole of their forces on a portion of those of the enemy. A shining example of how such a campaign may be successfully carried on is available for our study in the defence of Virginia by Lee. Repeated blows were struck at the enemy's vital points, fortifications were employed with rare tactical judgment, and on no occasion was any body of troops in fortifications allowed to be surrounded or cut off. Yet the defence was sustained against an army greatly superior in numbers and equipment for no less than four years. I shall deal later with some of the details of the tactical use of fortifications in that highly instructive campaign.

Torres Vedras, 1810.

Another such example is the Peninsular War. The Lines of Torres Vedras were planned with the highest tactical skill and admirably fulfilled their strategic end. But their communications were ever secure and their flanks unassailable. Nor was it by remaining behind them that Wellington defended Portugal. It was by skilful strategic movements and by constant blows, when opportunities arose, at the divided forces of the enemy, culminating in the great offensive campaigns of Salamanca and Vittoria, that Portugal, together with Spain, was finally freed of its invaders.

Therefore it does not by any means follow that because an inviting fortress exists an army should necessarily occupy it, nor because a locality lends itself eminently to defence that a force should entrench itself upon it. What a commander has to do is to ask himself what is the strategic end he has in view, and what are his relations to the rest of the forces on his own side? Is his action to be temporary only for the purpose of gaining time? Can he or should he rely on relief by other troops if he takes to fortifications, or has he only his own force to depend on for striking the offensive blow? On the answers to these questions depends the decision whether he should fortify or not, and the method in which he should fortify.

FORTIFICATION IN THE OFFENSIVE.

It is not only in defensive operations that fortification may be usefully employed; in the offensive also it can be most valuable. The conditions of modern war have rendered it extremely probable that in future campaigns field fortification will be extensively used in the attack. A frontal attack against good troops well posted has always been a desperate undertaking; it is now generally considered to be suicidal. The attacker has therefore to aim at the flanks of the defender's position. But attacks on the flanks must never be carried out without simultaneously holding the enemy in front, in order to prevent him from withdrawing men from his front to reinforce his flank or from moving out from his front against the attacker's communications. A position must therefore be taken up on the enemy's front to hold him to his place, and it is important that this should be done by as few men as possible, so as to set free the utmost possible number for the turning movement. It is evident therefore that field defences can play a most important part here. Again, we are now told, and the experience of the South African battles fully confirms it, that the attack on a position, whether accompanied by turning movements or not, will be a very long business, prolonged perhaps into several days. The aim of the attackers will be to develop the utmost possible fire effect against that part of the position which they select for attack; and to effect this they will endeavour to seize a position, or positions, whence such a fire effect can be developed. It may, and often will, be necessary to capture a series of successive positions before the main one can be attacked, and each position so secured must be immediately made good by fortification. It is evident therefore that in employing fortifications in offensive movements, the closest regard must be paid to the tactical conditions which prevail on the field of battle.

Although we have only recently realized the value of fortifications in the attack, yet there is actually nothing new in their employment in this connection. I shall presently give examples of their most extensive use in this manner so long ago as 1864, in the American Civil War.

IMPORTANCE TO ENGINEERS OF KNOWLEDGE OF STRATEGY AND TACTICS.

It may possibly be thought that these questions of strategy and tactics are not of direct interest to the Royal Engineer officer in his technical capacity. It might be said that they are rather for the consideration of the commander of the force, who, basing upon them his determination as to *when* and *why* to fortify, will instruct his engineers *where* to fortify, the latter confining their attention to the question of *how* to fortify, that is to the technical and constructive aspect of the matter. Such an idea is entirely erroneous—so evidently so that perhaps I ought not to assume that it is held by anyone. Still, it may perhaps not be considered entirely out of place, as it distinctly affects the subject under review, if I take the opportunity of discussing the question of the duties of Royal Engineers to their higher commanders and their relations to the other arms of the service.

There are several grounds for saying that the above view is a wrong one. Firstly, it is derogatory from the point of view of the functions of the Corps, because it reduces the Engineer from the position of a soldier, an active and intelligent participant in the operations of the battle, to that of a mechanic—a mere executor of another's ideas. But more important than this is the fact that it is on the Engineer officer himself that the commander of the force will often rely for advice on the tactical application of fortification to the conditions of the projected operation. The latter officer therefore must be fully qualified by his training and experience to give sound opinions based on correct tactical or strategic considerations.

Tactical Combination with the other Arms.

Nothing is more constantly impressed on us in all our official regulations and in all the utterances of our military leaders at the present day than the imperative necessity, if success in action is to be secured, of combination in the action of all the arms on the battlefield, whether in the attack or defence. This is just as important in the case of the Engineer arm as in the others. If the former plan their works without full consideration of the tactical conditions and the requirements of the troops who are going to use them, they may be found quite useless.

Koniggratz, 1866.

The following is an example of the evils that arise when, from defective training or defective organization, correct tactical combination in the working of the engineers with the other arms has not been secured. At the battle of Koniggratz, in the war between Austria and Prussia in 1866, the Austrian Engineers during the three days before the battle had thrown up a number of entrenchments and batteries. When the victorious Prussians were marching over the battlefield after the victory they found long lines of trenches which had never been occupied or made use of. There had been no tactical connection between the works and the troops; that is to say, the Engineers made the works, but apparently the corps and division leaders knew nothing of them or of the exact positions they were to hold; they extended far beyond the position intended, and the Commanding Engineer, riding round some hours after the battle had begun, found there were no troops near the works at all, and when they were occupied it was too late to stem the tide of Prussian victory. On the other hand several tactical points had not been put in a state of defence at all. A village on the right flank which commanded all the Austrian batteries on that face had been forgotten, and even the village of Chlum, the very key of the position, situated only a few hundred yards from the Austrian headquarters, was not prepared for defence, with the result that the Prussian Guard Corps were able to take possession of it with little opposition. These lamentable errors contributed greatly to the disastrous issue of the fight.

We see clearly here the evil results of the lack of tactical co-operation between the work of the Engineers and that of the other arms. It is necessary to bear clearly in mind that it is wrong to make entrenchments and then expect the fight to take such a course as will render them useful, but that we should make the positions of our entrenchments dependent on the probable course of the fight. In other words, do not fortify a locality because it is eminently suited to defence, but fortify only those positions which it is probable that the enemy will try and capture. These positions may perhaps be difficult to render defensible, but that is the greater reason for fortifying them.

There is yet another reason why engineers of all ranks should concern themselves with strategy and tactics. It is not only in the selection of localities for defence that such considerations come into play but also in the actual method of fortifying the locality, a responsibility that may often fall on junior officers. The position of the trenches and gun emplacements, the method of treating the flanks and the line of retreat, the cover for supports, the intercommunication between different parts of the position, even the actual profile of the trenches, are all dependent mainly on the tactical conditions of the case.

Preparation of a Defensive Position.

(1). SECURITY OF FLANKS.

The security of the flanks of a fortified position must be looked to very carefully, for it is on this as much as on anything else that the tactical strength of the position depends. If the position is for prolonged or permanent defence, it must be an all round position or have its flanks secured by impassable natural obstacles, such as seas or great rivers. If it is for temporary occupation only, then it must not be so placed that it can be easily turned, or it will be impossible to hold on to it long enough to fulfil the tactical end for which it is required. It must be remembered that a position with an unsecured flank can only be held for just so long as it will take the attacker to transfer part of his force on to the flank, and no longer; when that has been done the defender has the choice only between a speedy retirement and a disastrous defeat. If the nature of the country and the reconnoitring powers of the defenders are such that the attacker's movement to the flank can take place unperceived by the defenders, then annihilation will be the most probable result. As an example of this it is worth our while to glance at the battle of Chancellorsville in the American Civil War.

Chancellorsville, 1863.

The strength of the Federal army at the beginning of the Chancellorsville campaign was more than double than that of the Confederates, being in fact 130,000 men, with 428 guns, against 62,000 of the latter, with 370 guns; but the forces of the former were divided, and the number actually in position on the Chancellorsville line were approximately 90,000, against about 50,000 of the Confederates. The country in which these operations took place was densely wooded, almost impenetrable in places, with a few small patches of clearing. There was thus hardly any field of view in any direction. The Northern cavalry was inferior in numbers and quality to that of the South, and was less ably handled; the result of this, combined with the unfavourable nature of the ground, was that the Northern General, Hooker, was unable to obtain accurate information of the enemy's strength. Being under the impression that they had received reinforcements, and that their strength thus exceeded that of the force under his own immediate command, also seeing that they were concentrating to attack him, he deemed it prudent to take up a defensive position.

The position chosen is shewn on *Plate* I. The left flank rested on the Rappahannock river. Thence long lines of breastworks and trenches stretched almost continuously in a south-westerly direction to Chancellorsville, and from there westward in front of the turnpike road for two miles more. The whole line was nearly six miles from flank to flank. The position was one of great natural strength, surrounded on all sides by a dense forest filled with a tangled undergrowth, in the midst of which breastworks of logs had been constructed, with trees felled in front so as to form an almost impenetrable abattis. The artillery swept the few narrow roads by which the position could be approached from the front, and commanded the adjacent woods.

Soon after dawn on the 2nd May General Hooker rode round his lines and examined the works. As he looked over the barricades while receiving the cheers and salutes of his men, he was heard to say "How strong! how strong!" Yet, there was an element of fatal weakness which he failed to perceive, though it was known to his watchful enemies; and at that very moment a powerful force under his most redoubtable adversary was in full march on to the weak point.

It will be seen from *Plate* I. that the right flank was entirely unsecured. It neither rested on an obstacle, nor was secured by works, and it would seem that the idea of attack from that quarter never entered the heads of the defenders. The Confederate commander, Lee, had been informed by his cavalry the day before of this state of affairs, and he immediately resolved to take advantage of it by a daring manœuvre. He dispatched the famous Stonewall Jackson with an entire army corps by a circuitous route to attack the right flank of the Northern line, while he himself with but two divisions held the enemy in front with an entrenched position. Here we have an example of the proper use of fortifications by a force engaged on the offensive—to hold the enemy in front while a great turning movement is being carried on.

At 4 a.m. Jackson's corps started off by a narrow forest road, and when it was day the two divisions left behind engaged the attention of the enemy by a brisk demonstration. Though the turning column was observed by the Federals as it filed away to the south-west, the movement was only thought to denote a general retirement of the Confederate forces. Some troops were moved to the front to harass the supposed retreat and develop the situation, but these were held in check and the movement proceeded uninterruptedly. All day long the column marched in intense heat and dust. Notwithstanding the great delay entailed in moving an army corps by a single narrow forest road, and deploying it for battle, the density of the forest and the absence of the Northern cavalry prevented the movement being discovered. At 5.30 p.m. 25,000 Confederates were drawn up in battle array across the turnpike road within a mile of the flank of the Federal works, overlapping them to north and south; and not a single general in the Northern army had the least idea of their presence. At 6 o'clock the signal was given and the lines dashed forward to the attack. The 11th Northern Corps, holding the trenches on the right, were doubled up and fled panic struck on the centre. The attack was pressed vigorously home and swept away all bodies of troops who attempted a stand. More to the east the Northerners, warned by the noise of the conflict on the right, took up fresh positions and fought stubbornly; but for three hours the Confederates continued to advance through the thick undergrowth, while the remainder of the force, under Lee, vigorously attacked the more easterly portion of the Northern lines in order to prevent the detachment of reinforcing troops from that quarter. At length darkness, with its attendant confusion, and the fall of the Confederate leader, Jackson, caused a lull in the attack. During the night the Federals counter-attacked, but without success; they also threw up fresh entrenchments facing west, and brought up more guns and reinforcements of men. In the morning however these positions also were carried, and the victorious Confederates reached and occupied the heights above Chancellorsville.

There is no need to follow the operations further. Other forces of both sides were drawn into the combat and the fighting continued for four days, at the end of which the defeated and demoralized Northern army, having lost 17,000 men, escaped by the bridges and fords over the Rappahannock. They had been driven from a strong position by a force of half their strength. This result may be directly traced to the neglect of the right flank, and to the fact that the dense nature of the country, and the absence of the cavalry, prevented the attackers' movements from being discovered.

Both of these causes give us valuable lessons. A clear field, not only of fire but also of view, is one of the first essentials of a defensive position; and where the nature of the country is such that the latter cannot be secured, the want must be compensated for by most effective reconnaissance and scouting.

The methods of securing a flank are various, and need not be described in detail. If no natural obstacles exist works should be constructed facing towards the exposed flank, but in planning them care should be taken that they cannot be enfiladed from the front. Works facing to the front but well retired from the main line—as it were in echelon—will sometimes form an effective defence for a flank, particularly if their existence can be concealed from the enemy, for they will be able to bring a flanking fire to bear on him if he makes a flank attack. In other cases the defence of the flanks may be entrusted to, or at all events materially assisted by, fire from another fortified position at a distance, if the ground is open between them. Thus two such positions mutually protect each other's flanks.

Before leaving the important subject of flanks, it is as well to mention what is a secure natural obstacle. Rivers, mountain ranges and marshes are not in themselves absolute obstacles, if they can be crossed or passed round by a detour. Even the sea is not an absolute security, if the attacker has the command of it and can land troops at a point in rear of your line of works. But such obstacles, though not a permanent bar, are often sufficient to fulfil the strategic end, for they cause delay to the attacker, the amount of which will depend on the difficulties entailed in overcoming the obstacle or the length of the detour required to pass it. Thus where the defence is only required for a time such obstacles will suffice.

Occasions will sometimes however occur when absolute and permanent security is required for the flanks, as is the case of a base of operations. Such security can hardly ever be obtained except by the sea or a great river, and then only when these are commanded by the defenders' war vessels. Of this nature were the flanks of the Lines of Torres Vedras, secured by the sea and the Tagus respectively, and the position served as a perfectly secure base during the whole Peninsula War.

(2). LINE OF COMMUNICATIONS.

Next to the flanks the line of communications is perhaps the most important point to be looked to. In nearly all fortified positions the security of this line is of great importance, either to permit of the defenders retiring by it, or to allow of the arrival of supplies, reinforcements, or perhaps of a relieving force. Every possible effort should be made by a force on the defensive to prevent itself being surrounded and its communications cut; for should such an eventuality arise it is strategically dead, unless another force comes to its relief before its supplies or ammunition are exhausted.

If the defensive action is to be of a very temporary nature, and you contemplate making a bolt when your object is affected, as in the case of rear guards, the security of the line is of particular importance. You must see that the ground over which the retreat will take place is not covered by the enemy's fire—at all events for a considerable distance—and that it is quite free of all impediments to a rapid flight. Thus, for instance, all wire fences in rear of the positions must be cut, streams and rivers bridged or the fords marked and the banks ramped for the passage of artillery, passages cut through woods, hedges, etc., and the line of retreat well reconnoitred.

Similarly, if you expect to receive support from other troops, you must see that the ground over which the support will come is not commanded by the enemy's fire. If it is, the enemy in these days of rapid and long range fire will be able absolutely to prevent your supports reaching you.

Complete facilities must be provided for rapid communication between all parts of a fortified position, and from the position of the supports and reserve to the firing line. These must be out of sight of the enemy. In permanent defences they would be metalled and graded roads, with bridges; and in great fortresses there would be railways in addition. In field positions the result would be obtained by the removal of obstacles to the movement of artillery in the required directions, and by making paths for infantry in places where, on account of the ground being rocky, precipitous, intersected, wooded or marshy, movement would be difficult. Some work would in certain cases be necessary to conceal the communicating roads by sinking them in cuttings and putting the spoil on the side next the enemy; and, in the vicinity of the firing line, that is, to the latter from the position of the supports, the communication must be by trenches, zigzagged to avoid enfilade.

Shelters for Supports.

Covered shelters for the supports, some way behind the firing line, are essential. It should be remembered that it will not suffice in the present day to put the supports in the open on the reverse slope of a hill, unless the latter be very abrupt. It is certain that the enemy will make a point of searching with shrapnel the reverse slope of the hill behind the defended position, particularly during the infantry attack; so shelter against shrapnel, and zigzag trenches of communication, are necessary even where out of sight of the enemy. In permanent fortresses, where attack by siege guns firing high explosive shells is contemplated, it may be advisable in some cases to provide bombproof shelters and underground communications, particularly in exposed situations.

(3). POSITION OF INFANTRY TRENCHES.

I have already mentioned that tactical, or perhaps strategical, considerations will indicate the localities that should be fortified. There now remains the question of the actual position of the infantry trenches and works. This too is dependent largely upon the tactical conditions.

A hill or ridge generally forms an inviting position for defence, and instinct will usually lead one to select the top or crest of it as the position to hold. This course would however as a rule be inadvisable, as invisibility would in most cases be impossible to secure in such a position. Some way down the forward slopes, or even at the bottom of the hill, would be much better for invisibility; and the latter position would also permit of more complete development of the destructive effect of the low trajectory of the modern rifle. Care however must be taken not to sacrifice view or field of fire. This is where a tactical consideration comes in:—Is the position for passive and prolonged defence, is it intended to withdraw from it after a while, or will it be necessary to bring supports up to it during the last stages of the attack? It is a question in fact of the security of the lines of retreat and support, which has already been referred to. It will certainly be impossible for supports to reach you under fire, if they have to come down the front slope of a hill, and it would be still worse to have to retreat up it. A trench, even a zigzagged one, up the hillside would obviously be useless. Inequalities of the ground may however sometimes admit of communication from the rear being obtained round the flanks of the hill. A communicating trench leading from the firing line into some ravine or hollow, or to the rear of some wood or other protection from view, would effect what is required; it should however be concealed as far as possible.

If the hill is fairly flat topped, a good position may sometimes be found on the top of it and well back from the forward crest, preferably on the rear edge. In such a position invisibility can often be obtained, and it may even happen that the enemy will be unable to bring artillery fire to bear upon it. The great advantage however is that supports can be kept close up in rear and that retirement is easy; so when the defence is to be of a very temporary nature, followed by a rapid withdrawal, a position on the rear crest of a hill offers certain advantages. Against these however must be placed the disadvantage that the field of fire is comparatively short, though this is of less importance in these days of rapid-fire rifles than it used to be. This defect must be compensated for by ensuring that the front is free of cover for the enemy, and by providing a strong line of well concealed obstacles. With such a position there is bound to be a certain amount of ground, down the front slopes of the hill, which is hidden from the firing line. As the enemy will use this ground to mass his troops preparatory to a rush over the top, it is very desirable that it should be under fire, either of rifles or guns, from some other position away to a flank.

(4). PROFILE AND TRACE OF WORKS.

On the actual section and trace of the works I do not propose to touch except lightly. In the first place it is of far less importance than the tactical considerations which I have already mentioned. In fact it is hardly too much to say that, provided certain elementary requirements are fulfilled, it does not really very much matter what the section or trace is. At all events so long as adequate cover and facilities for the effective use of the rifle are provided, considerable latitude may be allowed as to the exact pattern of the works constructed, and it is undesirable to make any hard and fast rule.

In this matter again tactical considerations will afford guidance. The section, trace, composition, etc., must depend broadly on the weapons which the enemy will bring to bear against us, on the tactics of the attackers and on the temperament and characteristics of their soldiers and their leaders. If the enemy is a civilized army of the European type, armed with modern artillery, he will endeavour to bring such a storm of projectiles—mostly or perhaps entirely shrapnel—to bear on our parapets that we shall be forced to keep our heads down while his infantry is advancing to the attack. The defenders will in such cases make use of trenches of narrow section and low relief, and above all will aim at invisibility, which it is hoped will neutralize the action of the hostile artillery by depriving it of a target to lay on. Head cover, that is sandbags or stones on the parapet, gives valuable protection against shrapnel, and enables the defender's fire to be kept up. In extreme cases, where the defensive position may be commanded by that of the enemy, overhead cover with loopholes may be necessary. Planks and earth are sufficient against shrapnel, but are not effective against high explosive shell. These things however make invisibility difficult to attain, and in such cases one must weigh the *pros* and *cons* and decide which to sacrifice. Really complete invisibility is probably as effective as head cover, as the enemy does not know where to aim.

(5). GUN POSITIONS.

As regards the positions for guns no rules can be laid down. To ensure complete co-operation with the gunners who are to use them it will always be advisable to obtain the assistance of an artillery officer in selecting the positions and deciding how to treat them. Here again facilities for rapid and concealed bringing into action and retirement of the guns are essential, and invisibility is of more importance than the actual nature of the cover provided ; in fact guns in the open, if the surroundings are broken up by bushes or rocks, will probably suffer less than those which are advertised by newly thrown up parapets.

When the enemy has no artillery, as in the case of the uncivilized tribes against whom we often have to wage war, the tactical conditions will be different, so the defensive measures may be varied to suit them. We have no longer to fear in the attack the organized combination of infantry and artillery, which would be employed by a continental army, so invisibility is not of the same importance. If the position is for prolonged or permanent defence it will usually not be possible to keep its existence secret, and invisibility will be unnecessary. Towers or blockhouses are then best for small bodies and strong walled enclosures for larger ones. It is important that the walls should be flanked and plenty of obstacles provided.

In *field* operations against uncivilized foes fortifications will be of use in outposts and rearguards, and occasionally for temporary holding operations during an engagement. Here it will often be worth while to adopt many of the measures advocated against civilized troops, including invisibility. The result of the latter, at all events on the first one or two occasions, will probably be a successful ambuscade, with the consequence that during the rest of the campaign one's outpost positions will be left severely alone.

(6). TACTICAL SURPRISE.

In fact in all forms of warfare, and against all sorts of foes, it is difficult to overrate the importance of tactical surprise. War is a contest of wits, rather than of weapons. It should always be sought to "mystify, mislead and surprise" as Col. Henderson has told us was Stonewall Jackson's advice and practice. That this can effect valuable results on the defensive as well as in the attack is exemplified by what occurred to our troops at Magersfontein, Colenso and a score of minor actions in South Africa. It is often a good plan to dig trenches and then not occupy them, but to put your men behind rocks and stones some way off; or to form the spoil from your sunken trenches into false parapets at a distance. In short, every effort should be made to lead the enemy to believe that you are not where you are, and that you are where you are not.

(7). OBSTACLES.

It is unnecessary to dilate on the great importance of clearance of the foreground and provision of obstacles, particularly the former, which is essential under all circumstances. Obstacles require to be used with judgment and in conformity with the tactical conditions. By daylight, with an open field of fire for 600 or 800 yards, the most effective obstacle is the defender's fire, and no other is needed. Where however the field of fire is short, an artificial obstacle should be provided. Also where a night attack is possible, particularly in isolated situations and outpost positions, obstacles are most necessary, and they should be close in front of the defender's position. For day use however the line of obstacles should as a rule be farther out, as it is desirable to arrest the enemy's advance before he reaches close quarters, so as to prevent him establishing a superior fire effect at decisive range. The existence of the obstacles should come as a surprise to the attackers, so they should be well concealed and of course under the fire of the defenders.

(8). EXAMINATION OF FRONT OF POSITION.

In view of the intimate connection which exists between the tactical conditions of the field of operations and the defensive measures to be undertaken, it is evidently of great importance that the officer on whom devolves the responsibility of planning the latter should make himself thoroughly acquainted with the former; and to this end it is necessary that he should closely examine the ground, not only in the immediate vicinity of the proposed position but also to the front, flanks and rear. It is above all desirable that he should personally go to the front, if time and the absence of the enemy admit, and carefully examine the ground over which the attack will come, if possible as far as their probable artillery positions. From there he will be able to see in what positions he is most likely to secure invisibility for his firing line. He should further note whether there is any covered ground, ravines, etc., within musketry range, along which the attackers could make an unseen approach to the defensive position. Such ground is often not to be discovered from the position itself, and its presence is a source of great danger. If such exists some men should if possible be placed in a position whence they can bring a fire to bear into it. At all events it should be closely watched, and if there is any suspicion that it is being used it should be searched by shrapnel.

There is another point which should be noticed when examining the ground over which the attack will come, and that is whether facilities exist for local counter-attack. A ravine or other covered ground may permit of the defenders getting unseen on to the flank of the attackers, and a communicating trench from the defender's position into such a ravine would be useful.

(9). SECOND LINE COVERING FIRST.

Lastly it is desirable to make arrangements with regard to what to do should the attackers succeed in gaining possession of any portion of the defensive line. In such an event the action to be taken is to bring a heavy fire to bear on them from some point in rear of the main line, and under cover of this fire to make without the slightest hesitation or delay a vigorous counter-attack with a strong body of reserves in close formation, before the enemy have had time to recover from the confusion of the assault or obtain cover. To this end it is necessary to prepare some firing positions for infantry and artillery in rear of the first line, and if possible commanding it, whence this fire can be brought to bear, and also where possible to arrange the works of the first line so that they can be fired into from the rear. The necessity for cover, close in rear of the main line, for the reserves who will make this counter-attack has already been mentioned.

Moment for Counter-Attack or Retreat.

There is one other point which, though it is not directly connected with the preparation of a position for defence, is of sufficient importance to deserve mention here, as it concerns the correct tactical and strategic employment of the defensive position. During the course of the action the commander should be ever on the watch for the psychological moment when he should abandon his defensive tactics, either for attack or retreat. It is possible that the instructions he has received from superior authority will enable him to judge without difficulty when this moment has arrived, but if not he must judge it for himself from his appreciation of the tactical or strategic situation. This is not always easy, but it is most important, as disasters may sometimes arise from holding on to a defensive position too long and also from not holding on to it long enough. In the former case the disaster is generally to the defenders themselves, in the latter often to others of their own side. This consideration applies with as much force in the case of prolonged defensive operations, such as sieges of towns, as to temporary defences on the battlefield; in the former it is governed by the strategic situation, in the latter by the tactical. The operations to which I am now about to refer afford good examples of the former case.

American Civil War.

Two important and instructive campaigns occurred in the great American Civil War. One of the most marked characteristics of that war was the employment of field fortifications on a scale that has never been equalled on any other campaign either before or since. As with us in our recent contest, so in the beginning of the Civil War, the Americans made no use of Field Defences, had little experience of their value, and disliked the labour entailed in making them. But as the war progressed they discovered, as we did, the great increase of defensive power conferred by entrenchments, and in the last two years employment of these was universal, both in the attack and the defence. The rank and file required no orders, but immediately on occupying a position, even a temporary one during an attack, proceeded of their own accord to throw up cover of whatever kind the nature of the country permitted. Great ingenuity and skill were exhibited in these works; in wooded country they consisted of breastworks about four feet high, of logs or felled trees, with earth thrown up in front and abattis of felled trees as obstacles; in open country they were ordinary trenches. They soon learned too the best positions for the works, which, if further time admitted, were so strengthened as to be impregnable against frontal attack, and which sometimes extended for many miles in length, thus necessitating most extended turning movements and prolonging battles into affairs of several days', and even weeks', duration.

Atlanta Campaign, 1864.

The first of the campaigns of which I propose to speak is that of Atlanta in 1864 (*Plates* II., III. and IV.), nearly three years after the beginning of the war. At its commencement the Federal army, which was commanded by General Sherman, one of the most capable and dashing leaders of the Northern side, consisted of about 100,000 men (of whom 6,000 were cavalry) and 254 guns. The Confederates, even after all their reinforcements had arrived, only numbered about 75,000 (including 10,000 cavalry) and 187 guns. The latter were commanded by General Joseph E. Johnston, a commander of great experience and considerable tactical ability who, however, in his strategic methods was somewhat more inclined to prudence and caution than to a bold offensive.

The Federal army was encamped round Chattanooga (*Plate* II.); the Confederates occupied a strong defensive position in the neighbourhood of Dalton, some 40 to 50 miles south of the former place. Sherman's object was first to defeat Johnston's army, and second to obtain possession of Atlanta. The strategic importance of Atlanta was derived from it being an important railway centre, in or near which four lines had their junction. Its occupation by the Federals would sever the last remaining link between Lee's army, operating in Virginia, and the southern states of the Confederacy, and so cut off the former from large and productive districts whence it drew supplies and reinforcements.

Sherman's movement began on the 4th May, 1864. Finding that Johnston's position was of very great strength—for, not only was it strongly fortified, but the mountainous and precipitous nature of the country added greatly to its defensive capabilities—he decided not to waste time and men in fruitless attempts at frontal assault, but to try and turn the left flank. He accordingly despatched General McPherson, with one of the three corps into which his army was divided, by a circuitous and difficult route, *viâ* Snake Creek Gap, towards Resaca, a point 18 miles in rear of Johnston's impregnable position at Dalton. At the same time he distracted the latter's attention from the turning movement by skilful feint attacks on the front of his position. As soon as Johnston discovered that McPherson was at Snake Creek Gap, and that a turning movement was in progress, he rapidly evacuated (on the 12th May) his position at Dalton and, before Sherman had time to deliver a blow at him, had occupied a fresh position, which he had prudently prepared in advance, at Resaca. Thus the attackers were again faced with a strong defensive position in their front.

We have here another example of what I have already mentioned to you, namely, that a fortified position, however strong, can only be held for just so long as it takes the attacker to turn its flank. In this case that time was from the 4th to the 12th May, that is eight days.

For the rest of the time he was in command Johnston repeated the same tactics again and again. We read that "he adopted a plan of carefully entrenched lines, one succeeding the other as he might be compelled to retire. He practised a lynx-eyed watchfulness of his adversary, tempting him constantly to assault his entrenchments, holding his fortified positions to the last moment, but choosing that moment so well as to save nearly every gun and wagon in the final withdrawal, and always presenting a front covered by such defences that one man in the line was, by all sound military rules, equal to three or four in the attack."

Sherman however with even greater skill adopted corresponding measures in his attacking operations. He abstained from costly frontal assaults, but by a skilful use of field fortifications he held the defenders to their positions in front, and detached strong bodies round one or other of their flanks, thus manœuvring them out of each successive position and steadily forcing them back upon Atlanta. His operations are a model of the proper use of fortifications in offensive warfare.

The *Plates* shew the general lines of the campaign. On being confronted by a fortified line the Northern troops would seize and entrench another line, facing that of their enemies and as near to it as the ground allowed. They would then extend their entrenchments towards the flanks, particularly to that side which Sherman had selected for his flanking movement. The defenders would make a corresponding extension of their lines, prolonging them so as to head off the attackers in their efforts to gain the flanks or line of communications. You can see clearly on *Plate* III. the effect of this stretching out towards the flank by both parties. It is evident that the extent of this prolongation must sooner or later be limited by the great diminution it entailed in the strength of the troops holding the centre of the position. If these were dangerously attenuated they would be liable to fall to a frontal attack. This state of affairs was bound to come about with the Confederates first, since they had a considerable inferiority to the Federals. The latter would then be able to prolong further than the defenders and thus arrive on their flank. When this had been achieved Sherman would despatch a portion of his reserves round to the flank with the intention of making an attack, and the defenders would have no option but to accept battle, under circumstances that could only lead to disaster, or to evacuate their defensive position.

The latter was always the course chosen. Long before the time arose for the retirement Johnston would choose a favourable position in rear for his next stand, and have entrenchments thrown up there. Thus when the retirement took place it was timely; it was carried out in good order and nothing was left behind.

Throughout these operations there was constant fighting and skirmishing all along the opposing lines, in fact the whole campaign was one long battle, in which at times the fighting was very stubborn. Great delay was caused to the Federal advance, but by the middle of July the Confederates had been pushed back across the Chattahoochee river and had taken up a defensive position extending for about six miles along the south of Peach Tree Creek, facing north, and thence for about three miles, facing east, as far as the Georgia Railway (*Plate* IV.). This position was only about two to three miles outside the city of Atlanta itself, around which a circle of entrenchments had already been prepared with a view to resist a siege.

At this juncture General Johnston was removed from the command of the Confederate army and his place taken by General Hood. For some time past the President and people of the Southern Confederacy had been dissatisfied with the former's purely defensive strategy and his failure to take offensive action. Putting aside the question of whether it was wise to swap horses when crossing a stream, it must be admitted that they had good grounds for their dissatisfaction. Johnston's strategy would have excellently served the purpose if his force had been a rear guard, or if nothing but delay was wanted in order to admit of reinforcement or strategic action by another force ; but in the case of an independent army without prospect of external aid it was quite unsuitable, since the defeat of the enemy is the sole aim of such a force and this cannot be achieved without offensive action. We know how Lee and Jackson, with greater disparity of numbers than Johnston, succeeded, by skilful offensive action, in keeping the Northern armies in Virginia at bay for years.

On the 20th July Hood vigorously attacked with superior forces a portion of the Federal army at Peach Tree Creek, before the latter had established a fortified line and while it was partially isolated by reason of a wide turning movement to the east being in progress. The fighting was stubborn, but Sherman hurried reinforcements up and the Confederates were finally repulsed with a loss of about 6,000.

On the 22nd the latter retired into their lines round Atlanta, and simultaneously Hood despatched four divisions by a long detour to attack the extreme flank and rear of that portion of the Federal army which had established itself on the east side. The attack was very near to being a success, and had it been so would have led to important results, but it was repulsed with a loss to the Confederates of not far short of 10,000 men.

After this the Federals pushed their lines of entrenchments as close up as they could to the defenders' lines, and prolonged them away to the west. On the 29th another attack was undertaken by Hood, this time on the west side at Ezra Church, on some Federal columns that were in motion to turn his left flank. This too was unsuccessful, and the severe losses sustained in this and the previous assaults led him to abandon such modes of warfare and revert to simple defensive tactics.

The fortified lines on each side stretched away further and further to the south-west, the attackers aiming at the Confederate communications and the defenders endeavouring to head them off. A constant pressure was kept up by the Federals on all parts of the defensive line opposed to them, the artillery bombardment was continuous, and no rest was allowed to the defenders day or night. At the end of August Sherman determined on a bold stroke. He practically raised the siege and, concentrating the whole of his army on his right—*i.e.* south of Atlanta—, moved it against Hood's communications. The latter made an attack during this operation on one of the positions covering the Federal movement (at Jonesboro'), but was again defeated with loss, and Sherman succeeded in establishing himself on the Macon and Western Railroad, south of the city, thus severing its last line of communication. Hood, recognising that the game was up, burnt his rolling stock and stores, blew up his surplus ammunition and, on the 2nd September, evacuated Atlanta in a northerly direction.

The operations thus briefly and inadequately sketched out are of very great interest, and merit much closer study than it is possible to give them in the short time of a lecture. The way in which the attackers established a line of works in front of those of the defenders, and both parties then stretched and stretched away laterally in the attempt to gain each other's flanks, is most instructive. This was the first time that such tactics had made their appearance in war, and it cannot be doubted that their adoption was due to their being found well suited to the weapons and tactical conditions of the period.

Our experiences in the recent war in South Africa are such as to justify the belief that they would be equally suited to the conditions of the present day, and it is more than probable that we shall see them repeated in the campaigns of the future.

Petersburg, 1864.

The operations of the siege of the lines of Petersburg in Virginia are another example of the same tactics. Indeed so great is the similarity that there is no need to go into them in detail, since an examination of *Plate* V. is sufficient to shew how they were carried out.

By the summer of 1864 the Confederate army under Lee, after three years of bold and skilful offensive action against superior forces, was reduced to practically passive defence in the immediate vicinity of Richmond. The previous unsuccessful attempts of the Federals on this city had been made on its north and east sides. This time they determined to invest it on the south side, with a view to severing its communications with the southern states and so preventing the entry of supplies. With this end they crossed to the western side of the James River, and endeavoured to capture the city of Petersburg, which lies about 25 miles south of Richmond, and in which several important lines of rail from the south converge. Petersburg had already been prepared for defence by the Confederates. Its fortifications consisted of a series of strong redans or batteries, encircling the southern and eastern half of the town at a distance of two miles. These were connected by infantry parapets with high profiles, and all had ditches.

The passage of the river was effected in the middle of June, 1864, and soon afterwards the works on the eastern face were assaulted in force. Up to then Lee had not anticipated an attack in force on the lines of Petersburg, and the garrison had been left very weak. The works therefore were carried in parts, though the fighting was severe and several of them changed hands more than once. The following day the Confederates retired to a more favourable and shorter line from 500 to 1,000 yards in rear of the first one, and proceeded to entrench it rapidly. They were also strongly reinforced. The Federals lost no time in attacking this line in very superior force, but were repulsed with loss. They proceeded however to hold and fortify lines close up to those of the defenders, in places not more than 100 yards distant from them; and both sides remained in these relative positions, with constant skirmishing and fighting, throughout the rest of the siege—a period of nearly nine months.

The Federals next proceeded to extend their lines to the west with a view to severing the remaining lines of communications. The Weldon Railroad was the next line aimed at, and it will be seen how the defenders endeavoured to secure it by stretching out entrenched lines in a southerly direction and by fortifying points on the line of rail itself.

In the meanwhile the attackers brought up a siege train of heavy rifled guns, and systematically undertook works of a regular siege. Only one more assault was attempted; and this was undertaken in conjunction with the explosion of a great mine, run under the defenders' works, which was however a total failure. After this they confined themselves to holding the defenders in front and moving continuously to the left.

The Weldon Railway was captured at the end of August. The defenders' next care was to protect their remaining lines of communication, (1) the Boydton Plank Road, by which supplies could still be brought in carts from a point on the Weldon railway beyond the Federals' sphere of activity and (2) the South Side Railway, running west. To this end they threw out a line of strong entrenchments running in a south-westerly direction for a distance of nearly six miles. An attempt made by the attackers in October to turn the outer flank of this line was a failure, and the Federals proceeded to make a corresponding line of entrenchments and extend it to the left.

During the winter the bad state of the country made movement impossible, so the operations remained at a standstill. By this time the condition of the defenders as regards supplies, equipment and men had become desperate, and it was hardly possible to renew them. In February the Federals renewed their movement to the left, and extended their lines in the same direction. At the end of March a strong force of cavalry and infantry under Sheridan captured the Confederate position at Five Forks, and continued their movement towards the South Side Railway.

By now the tension of the widely extended line of the defenders had become too great for their numbers. At all points it was weakly held, and was likely to succumb to an attack anywhere. Lee therefore decided to evacuate Petersburg and Richmond and move out westward to Danville, thence passing south to join the remaining forces of the Confederacy under Johnston. The siege therefore came to an end, and Petersburg and Richmond were occupied by the Federals on the 3rd April, 1865.

The mounted troops under Sheridan pressed on in pursuit and soon succeeded in heading off the Confederates; and very shortly afterwards the final scene of the long drama was enacted at Appomattox Court House, where Lee, with the famished and ragged remnants of his army, surrendered.

The Study of Strategy and Tactics.

I have now given, I think, sufficient illustrations of the tactical application of fortification in the attack and defence, and of the great importance to engineers of a knowledge of strategy and of the tactics of all arms. I would like, if I should not be thought presumptuous, to make a few remarks as to the best way of obtaining such knowledge. First in order of importance is the intelligent study of military history. Great campaigns should be analysed with a view to ascertaining the part played by fortresses and fortified positions in the strategic action. Detailed accounts of sieges and defensive operations should be examined, in order to see how far the position, nature and method of employment of the works were suited to the tactical conditions. The successful cases may be taken as examples and guides, the unsuccessful ones as warnings.

For the study of the strategic aspect of this question the campaigns of Napoleon form an admirable basis. No commander has known better than he the value of fortification, and to distinguish between what it can effect and what it cannot. His earlier campaigns clearly illustrate this, and a study of his later ones will reveal how the disasters that attended them were at least partially attributable to a neglect of this principle.

Another valuable study is that of Wellington's campaigns in the Peninsula. The part played by the Lines of Torres Vedras and the fortresses of Badajos, Ciudad Rodrigo, Burgos and San Sebastian form the very web of the strategic action of the war. For the tactical employment of fortifications no finer model can be found than the dispositions for the defence of the Torres Vedras Lines. The lessons to be derived from them are as applicable to the conditions of the present day as to the time when they took place, and this must always be the case where correct tactical principles have been followed. A study of these famous lines may fitly form the foundation of the education in fortification of every Engineer.

Coming to more recent times the American Civil War affords a mass of examples of the use of fortifications, more, probably, than the whole of the European campaigns of the nineteenth century put together. Besides the great campaigns of Jackson and Lee in Virginia, the operations in the states bordering on the Mississipi may profitably be studied, particularly those for the possession of the fortress of Vicksburg. Those which I have briefly touched on to-night also deserve closer examination. The Russo-Turkish war of 1877–78 is another which affords valuable lessons of the employment of fortifications, both in their strategical and their tactical aspect.

MODERN DEVELOPMENTS IN TACTICS.

Of equal importance to the study of past warfare is that of the conditions—the ever-varying conditions—of the present time. Naturally the recent war in South Africa, with its strange and unexpected developments, must loom large in our thoughts on this question. And here I would venture to sound a note of warning. We shall fall into error if we assume that the defensive forms and methods which were employed with success by the Boers and ourselves in that war will necessarily be equally effective in our next one. These things, as I have already explained, depend on the tactical conditions, and it is unlikely that in our next war the tactical conditions will at all resemble those of South Africa.

It is instructive to note that some Continental authorities by no means take the same view as we do of the lessons of the war. They do not share our belief that the failures of our troops in the assaults of fortified positions were due to the fact that modern weapons and smokeless powder have conferred increased strength on defensive works. They hold instead that the failures were attributable to faulty tactics and to the insufficiency of the attackers' artillery. They still believe that positions may be successfully assaulted by infantry, disposed, brought into the fight and supported with tactical judgment, provided they are assisted during their advance by the concentrated fire of powerful artillery, by means of which the defenders will be forced to keep below their parapets. Be this as it may, it is evidently well worth our while to examine carefully the grounds on which their opinions are based, lest we may find when too late that our own have been too hastily formed; and this is particularly necessary in view of the changes which are even now occurring in tactical conditions.

Napoleon said that tactics change every ten years, but the rapid development of modern armaments brings about changes even sooner than this. Even in the short time that has elapsed since the war the conditions have altered; and it is more than probable that we are now on the eve of a change in tactics as great and far-reaching as that which was brought about by the introduction of smokeless powder and magazine rifles. The factor which will probably cause this change is the introduction of quick-firing field guns fitted with shields, which have been adopted by some foreign armies and are. I understand, about to be issued to our own. Great expectations of its probable effects have been formed by those who believe in this weapon, and the tactics of artillery at all events will undergo a complete revolution. The general principles of the employment of these guns in the attack, adopted by the French who led the way in their introduction, are briefly as follows. The preparation by the artillery of a defensive position to be attacked will take place, not prior to the infantry attack, but during its progress, culminating in the utmost possible concentration of fire on it during the last stages, the fire being directed over it at the reserves at the moment of assault. The demoralizing effect is to be produced by the suddenness with which fire is to be opened, and by its rapidity and concentration for a few moments at a time. No time will be wasted in very accurate ranging, but the system of fire drill aims at delivering such a hail of projectiles—generally shrapnel—over a belt of ground 400 yards deep and equal in width to the frontage of the attacking artillery that the defenders, if within that zone, will be forced to keep under cover. This effect is obtained by delivering what is called a "rafale," that is eight rounds from each gun, with the elevation increased by 100 yards after every second round. As the gun can be fired at the rate of 17 to 20 aimed rounds to the minute, it is evident that the chances of hitting, and the effect, will be considerable.

It is impossible to pursue this subject further now, but I would strongly advise officers to investigate it fully for themselves, and see whether it will necessitate any modification of our present ideas as to defensive tactics.

At this moment it is impossible to forecast what even the immediate future has in store for our country. It is within the bounds of possibility that we may before long find ourselves involved in a struggle in which there will be arrayed against us the vast and highly organized armies of a European nation or nations. It is clearly the duty of every one of us to prepare ourselves for all eventualities. A diligent study of the history of the past, a close examination of the conditions of the present, and an intelligent forecast of the probable developments of the future, are the means whereby we may hope to solve the problems that will arise. At all events they will enable us to approach the latter with minds trained and judgments strengthened, so that, whatever part we are called upon to play, we may so bear ourselves as to reflect credit on the Corps to which we are proud to belong and be of service to the country which the wisdom and devotion of our predecessors have assisted to make great.

PLATE I.

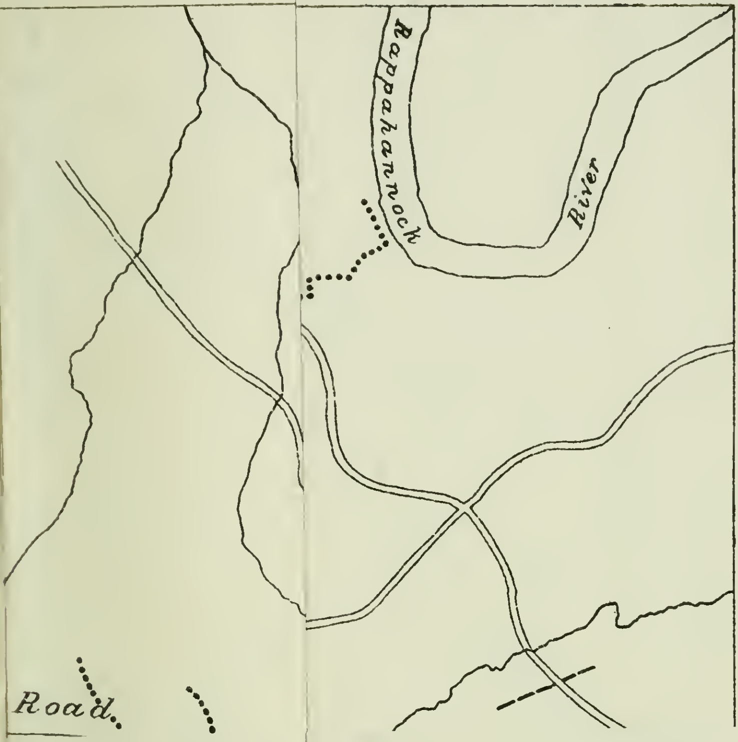


PLATE I.

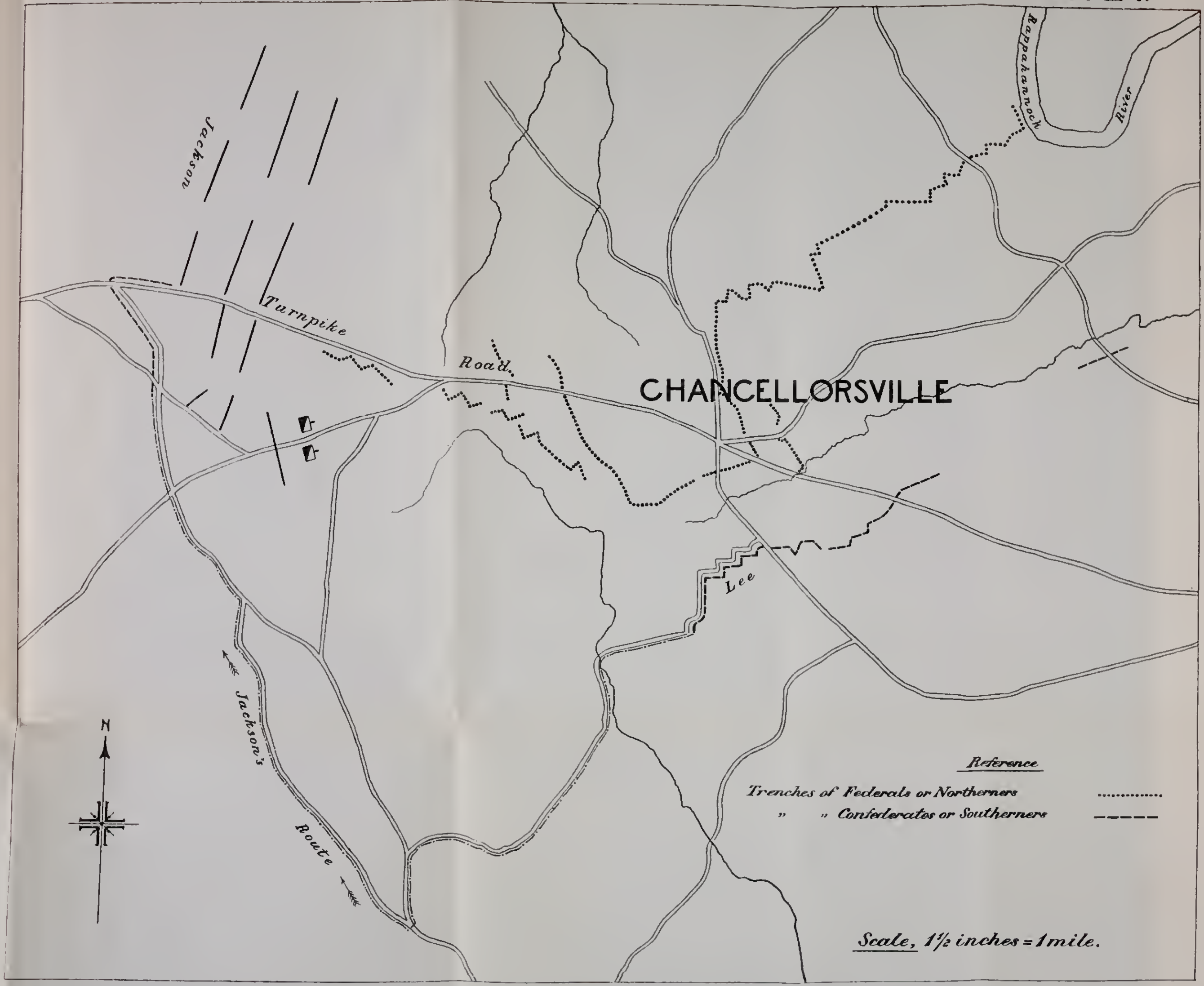

Jackson
Turnpike
Road
CHANCELLORSVILLE
Rappahannock
River
Lee
Jackson's
Route
N
Reference
Trenches of Federals or Northerners ....
" " Confederates or Southerners ———
Scale, 1½ inches = 1 mile.

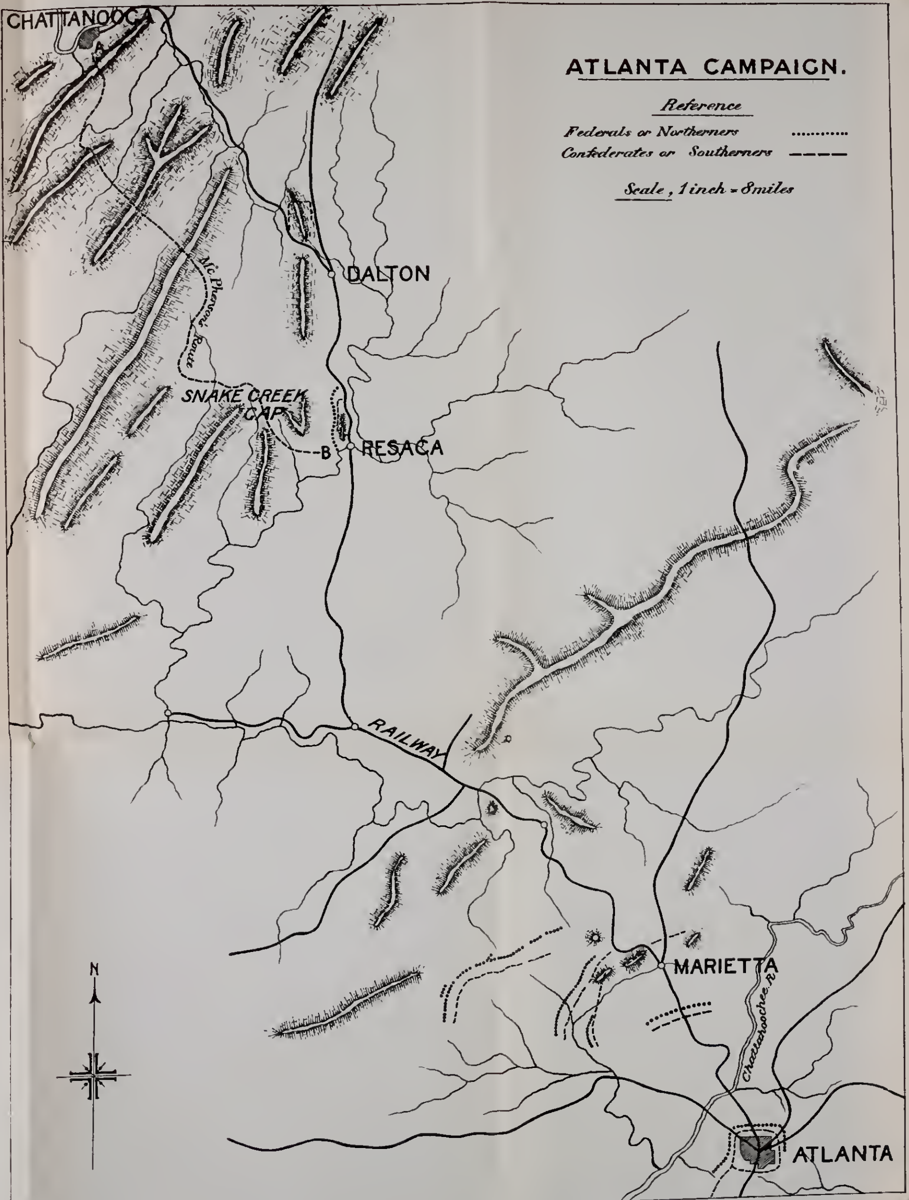
PLATE II.

ATLANTA CAMPAIGN.

Reference

Federals or Northerners	…………
Confederates or Southerners	– – – –

PLATE II.


ATLANTA CAMPAIGN.
Reference
Federals or Northerners ....
Confederates or Southerners ----
Scale, 1 inch = 8 miles
CHATTANOOGA
A
DALTON
McPherson's Route
SNAKE CREEK GAP
B
RESACA
RAILWAY
MARIETTA
Chattahoochee R.
ATLANTA
N

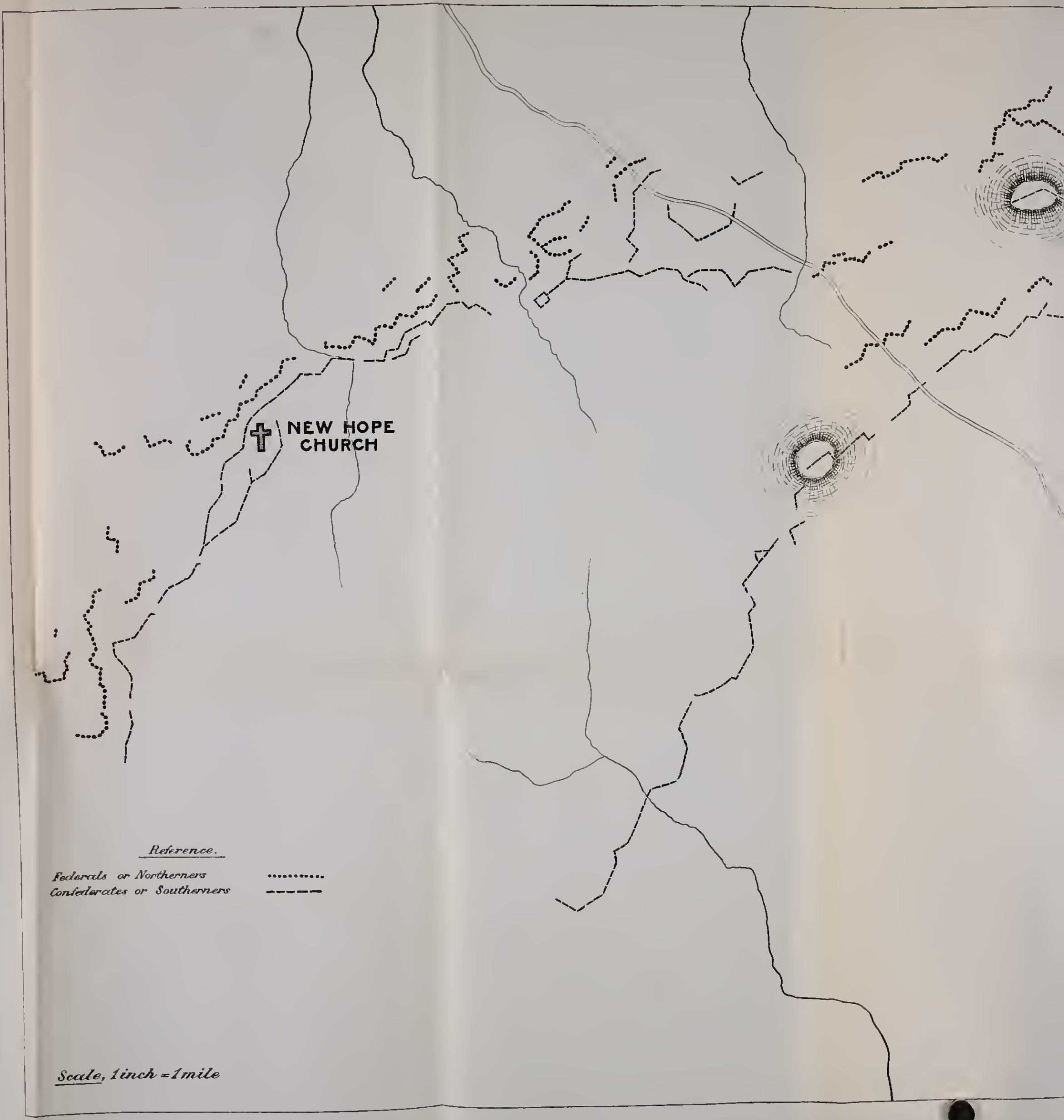
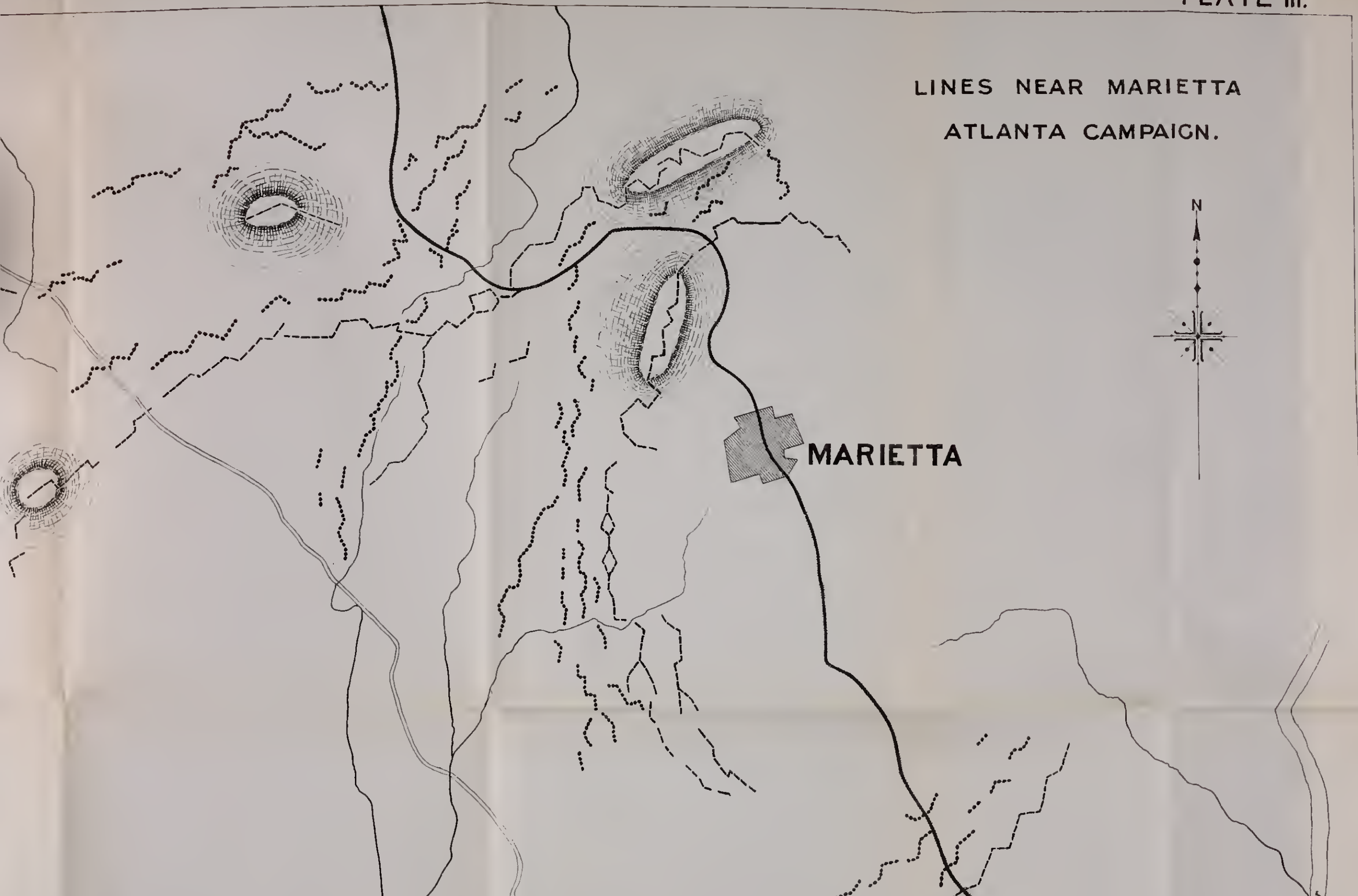

NEW HOPE CHURCH
Reference.
Federals or Northerners ....
Confederates or Southerners – – – –
Scale, 1 inch = 1 mile

PLATE III.



LINES NEAR MARIETTA
ATLANTA CAMPAIGN.

PLATE IV.

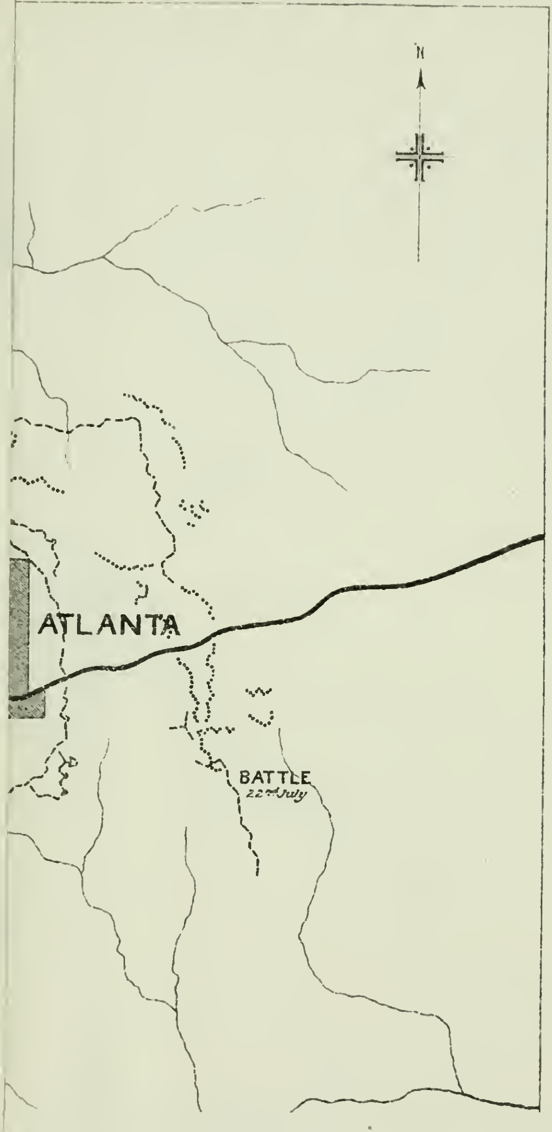
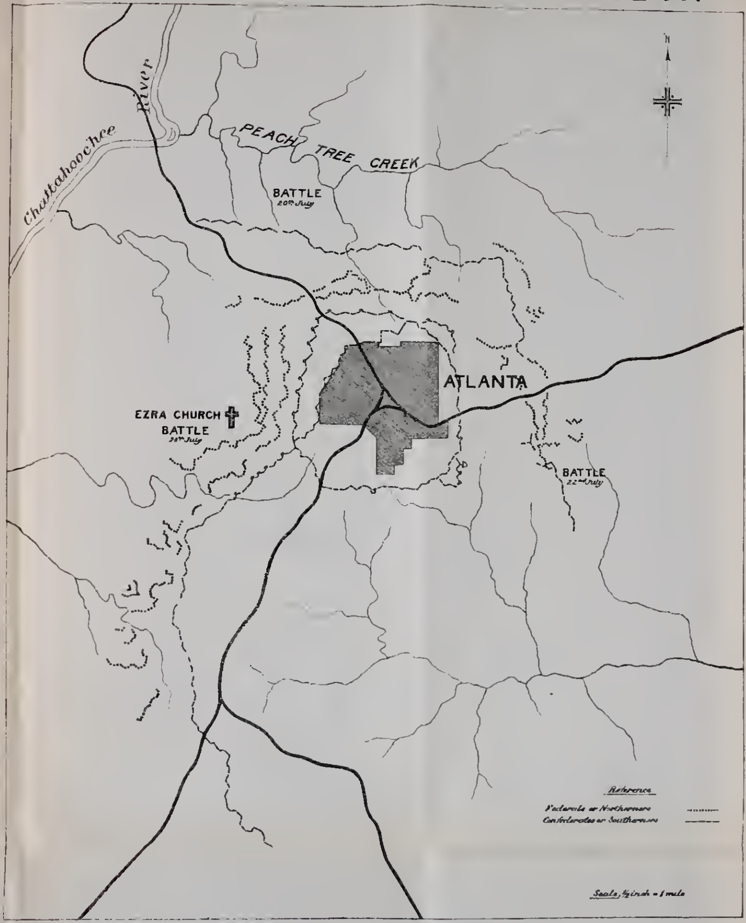
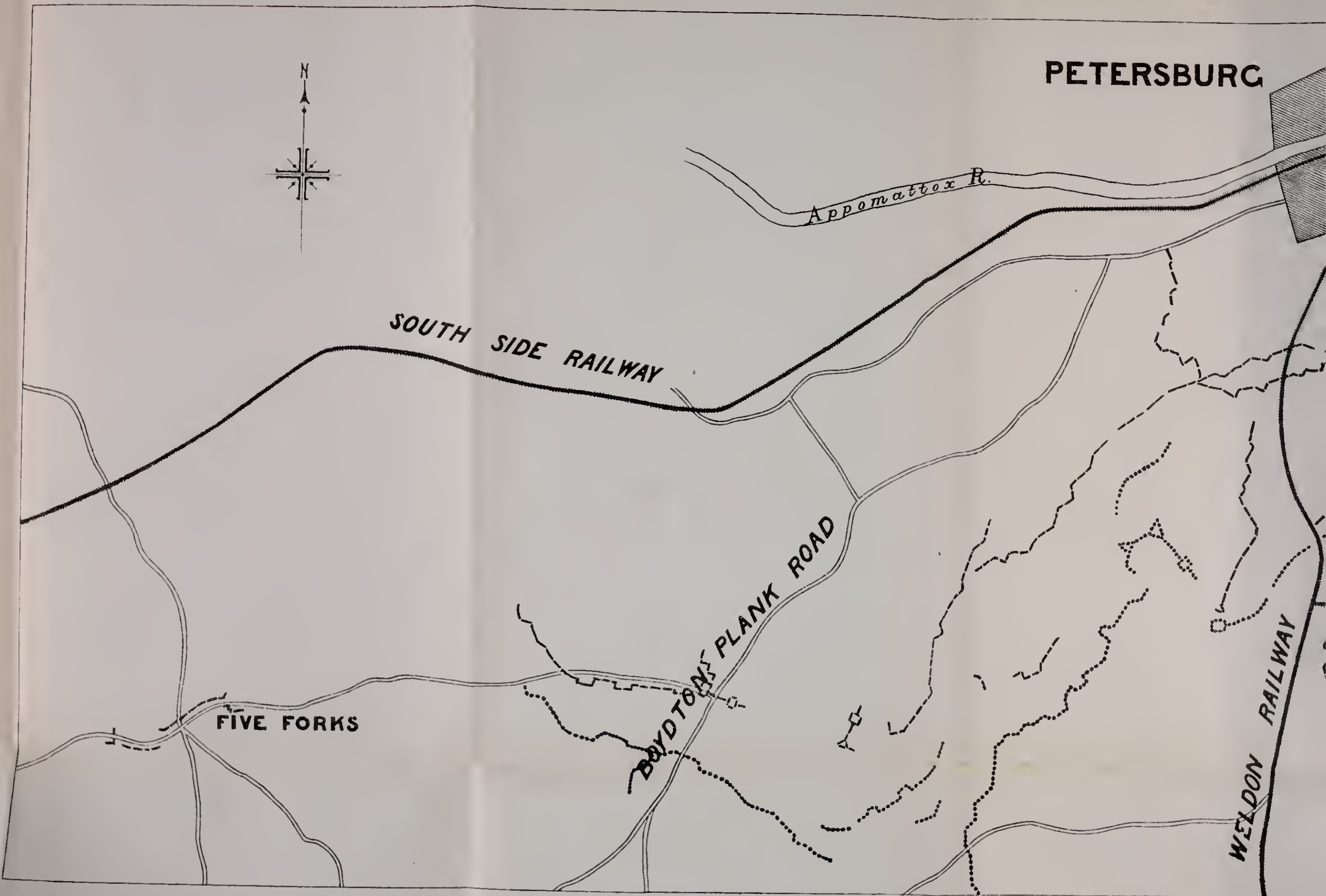


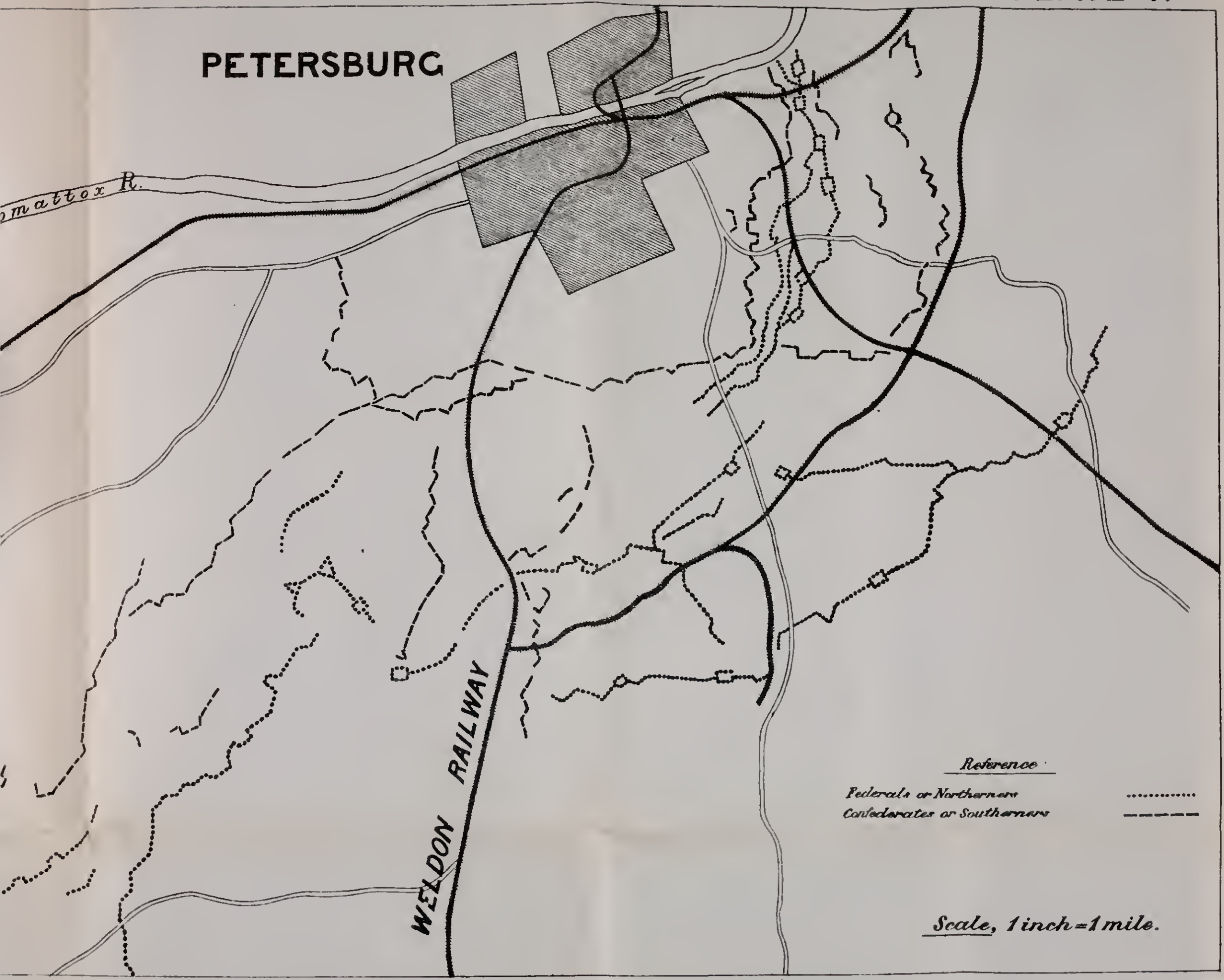
PLATE IV.


N
Chattahoochee River
PEACH TREE CREEK
BATTLE
20th July
ATLANTA
EZRA CHURCH
BATTLE
28th July
BATTLE
22nd July
Reference
Federals or Northerners ....
Confederates or Southerners – – – –
Scale, ½ inch = 1 mile



N
PETERSBURG
Appomattox R.
SOUTH SIDE RAILWAY
BOYDTON'S PLANK ROAD
FIVE FORKS
WELDON RAILWAY

PLATE V.


PETERSBURG
omattox R.
WELDON RAILWAY
Reference
Federals or Northerners ....
Confederates or Southerners – – – –
Scale, 1 inch = 1 mile.

PAPER IV.

PUMPS AND AIR LIFTS FOR RAISING WATER.

BY

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(*Lecture delivered at the School of Military Engineering, Chatham, on February* 11*th*, 1904).

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PUMPS AND AIR LIFTS FOR RAISING WATER.

INTRODUCTORY.

ALTHOUGH the title to this paper suggests that the modern system of pumping water by compressed air is to constitute the main subject dealt with, I must explain at the outset that the information available as to the theoretical and practical application of compressed air to raising water is not sufficient to absorb our whole attention during the time available.

I therefore propose to deal firstly with the design of pumping plant generally, illustrating various types of pumps suited to different conditions, and dealing with the question of "duty" and the method of calculating the efficiency of pumping machinery generally; and then to give a practical statement, based upon personal experience, of the present position and utility of the Air Lift Pump, with a reference to its application to military purposes in the field.

From the above remarks you will, I think, appreciate the fact that I do not propose to deal at any length with the purely theoretical aspect of the subject before us. As regards pumping machinery of the ordinary type, the theoretical laws are comparatively simple and all calculations are of an elementary character; while as regards the air lift plant, theory is at a loss to explain more than the primary and obvious law that a column of water highly charged with air is lighter than a similar column of water under natural conditions.

Part I.—Design of Pumping Plant.

Proceeding therefore to consider the practical conditions affecting the design, application and efficiency of pumping machinery, the principal factors are

(1) the level from which the water has to be raised,

(2) the level to which it has to be lifted,

(3) the quantity required,

(4) the amount of storage available both below and above surface level,

(5) the nature of the source, whether a river, collecting reservoir, well or boring,

and (6) questions connected with capital outlay, working expenses and cost of maintenance.

(1). Suction Level.

The question of Suction Level naturally arises first, and is of a simple character where the source is a river or subsoil collecting reservoir. Where, however, underground water is concerned, the determination of the depth at which the quantity required can be obtained becomes far more important and also more complex. The porosity of the strata, the natural head due to the relative elevation of the gathering ground, the depth and diameter and the freedom of access through the sides or bottom of the well or boring, are all-important factors, the combined effect of which can, in most cases, only be determined by direct experiment.

Thus in the first instance it is essential to give the most careful attention to the question of constructing a well or of relying upon a less costly boring for the supply required. Speaking broadly, it may be assumed that in a fairly porous or fissured strata, a boring will probably yield a larger supply *proportionately to the capital outlay* than a well; but where the water bearing strata is very compact, it is possible that the required supply will not be obtained without a well, with or without headings; and where sand is brought in by the flow of water, a well may be necessary to serve as a settling chamber for the sand.

Let me, in passing, briefly explain the purposes served by a well as compared with a boring. In the first place, a well gives access to the water bearing strata and enables headings to be driven to augment the supply if necessary, but it also presents a larger area in contact with the water-bearing strata proportional to the circumference. In the second place, a well provides underground storage by means of which pumping may be carried on (for limited and intermittent periods) at a rate in excess of the actual yield of the well. But the advantage most conspicuous in connection with our present subject is that a well permits of the use of a duplicate or triple pump, and all the difficulties connected with balancing the pump-rods, bucket, etc., are very simply overcome. In cases where the pump can be fixed above the "rest-level" of the water, or otherwise when the water can be shut out, a well gives access to the working parts of the pump and avoids the necessity for lifting the bucket, rods (and occasionally the pump itself) to the surface for examination, renewal or repair. Now, as a pump will not draw water more than 28 ft. below the "bottom" or "suction" valve, it follows that, unless water can be shut out of the well when desired, access to the pump can only be secured in cases where the lowest "pumping level" is within 28 feet of "rest level"; moreover, unless the actual "pumping level" has been previously ascertained by experiment (that is, by pumping at the full rate required for at least 14 days) it will obviously be desirable to fix the pumps at the lowest possible level, not only to secure the required supply but to provide for a possible fall of the water level after continued pumping.

To return however to the point under consideration, viz., the suction level of the pump. It is always desirable in each case to ascertain the lowest level to which the water is likely to fall when pumping at the full rate required, and to fix the pump barrel as near this level as possible. In the case of a boring there may be a fall of as much as 200 feet between "rest-level" and "pumping level"; and it will be seen how important this question becomes when deciding upon the adoption of a well or a boring, or on the other hand when designing the most suitable form of pump for any particular case.

As it is a very common difficulty, in testing the yield and "pumping level" of borings (where the pump probably occupies nearly the full area of the boring), to ascertain the level to which the water falls and the rate at which it is lowered, let me describe a simple means of ascertaining the water level where the ordinary float and line cannot be used. A small pipe of, say $\frac{3}{8}$ inch internal diameter, is either fixed to the outside of the pump and lowered with it or may be lowered afterwards if there is sufficient clearance. This pipe must terminate at some known depth and have an open end. The upper end of this pipe is connected to an air pump, and is fitted with a pressure gauge, preferably of large diameter and graduated to show pressures in feet head of water. By pumping air into this pipe the water is expelled from the lower end; and the pressure shewn on the gauge, after all the water has been expelled, will represent the difference in level between the bottom of the air pipe and the water in the boring. The former being known, the latter is obtained by a simple subtraction sum.

(2). Head on Pump.

The difficulties in connection with the Head on a Pump are of a much simpler character than those I have just dealt with. Where the water is pumped into a reservoir, the head of water is definitely ascertainable, the only uncertain factor being the friction due to the length and diameter of the rising main, and the number and acuteness of its bends. Where the capacity of the main is such that the maximum velocity of the water does not exceed 2 feet per second, the friction arising in any reasonable length (say up to a mile) is very small and may be neglected.

As affecting the design of the pumps, the main point to be considered is that pumps in wells or borings, being relatively inaccessible, should not be subjected to a greater head of water than is absolutely necessary. Thus where the top water level is more than 20 ft. above the surface, it is desirable to release the water from the underground pumps at ground level, and to provide other pumps to deliver it thence to the reservoir. Such pumps can be operated by the same engine that drives the low level pumps, but can be designed more economically, both as to first cost and cost of maintenance, than well or borehole pumps. Where steam is the motive power employed, this affords a convenient point for erecting the condenser. With regard to the use of a condenser in connection with pumping engines, I would point out that, with any reasonably economical steam engine, the rise in the temperature of the water delivered by the pumps, due to passing through or in contact with the condenser, will be very trifling and practically negligible; but on the other hand, in cases where the engine is used for driving other plant or is working extravagantly, the rise of temperature may be sufficient to cause inconvenience, particularly to the owners of breweries and maltings.

(3). Quantity of Water Required.

I need not refer in detail to the Quantity of Water required, as the calculations for the capacity of a pump are of an elementary character; but it will perhaps be advisable to mention one or two practical points. The elements affecting capacity are speed, length of stroke, diameter of pump barrel and whether working "single acting" or "double acting."

As regards *speed*, the average velocity of pump bucket should not exceed 150 feet per minute. Although there are pumps specially designed to permit a higher velocity than this, difficulties connected with the area of water passage through valves, and the too rapid reciprocation of heavy rods, buckets and couplings, impose a limit which no special design can overcome.

The *length of the stroke* is certainly more open to variation, and indeed is only limited by the design of the "headgear" or method of operating the pumps from the engine. If a crank is adopted a stroke of 3 feet is almost the maximum stroke possible, although by means of levers this can be increased to 4 feet or more. This however involves very heavy strains on the intermediate rods, pins and the crank itself. If no gearing is used, that is, where the pump is operated direct from the engine, the length of stroke can of course be increased without this disadvantage.

The *diameter of pump barrel* is only limited by the strains on the pump rods and, in the case of a boring, by its internal diameter. The former is governed by the "head" of water on the pump and the weight of the rods. In the latter case it must be remembered that borings, even when lined with tubes, are rarely truly vertical or of exactly similar diameter throughout. Thus there should be ample clearance between the outside of the pump and the internal diameter of the bore-tubes.

The question of using "*single-acting*" *or* "*double-acting*" *pumps* is one of much importance, as the capacity of the latter is of course double that of the former at any given speed. It may be assumed that, where circumstances are favorable, the "double acting" pump is preferable, as it secures steadier working and greater compactness of design; but triple plunger pumps, driven by belt or gearing or direct from the engine crossheads, are very convenient in many cases and have, moreover, the great advantage of simplicity.

(4). Amount of Storage Available.

Beyond the question of "pumping level," which I have already enlarged upon, there must be considered the question of Storage. The effect of a well has been referred to, but I will now illustrate the advantage as affecting the design of the pump. Of course where pumping is continuous, the capacity of the pump cannot exceed the yield of the well or boring; but continuous pumping is objectionable, unless alternative and independent sources of supply are available. If, therefore, pumping is carried on for (say) 12 hours out of every 24, a well holding one half of the daily supply required will enable the pump capacity to be increased to twice the *hourly* yield of the well,—assuming, of course, that the *daily yield* is equal to the *daily demand.* In cases where the daily demand is equal to the average daily yield, it will be seen that a well is essential, if continuous pumping is to be avoided.

The question of storage must further be considered in connection with the delivery of the water to the consumer ; in other words, the inequality between the hourly demand and the hourly yield at the source must be adjusted by means of storage. The demand in the case of a town supply varies considerably throughout the day ; and if the daily yield at the source is only equal to the total daily demand, it is clear that some surplus must be stored to meet the times of heaviest demand, such surplus being restored during the night or when the hourly demand is less than the hourly yield. Storage is also necessary to allow of intermittent pumping and to provide for accident or failure of the pumping machinery. For town supplies, it is desirable to provide storage for three days' requirements where the pumps are in a well or boring and only one source is available ; this may be reduced to two days' requirements where surface pumps alone are in use, and to one day's requirements where duplicate sources of supply are available.

(5). Nature of Source.

Nature of Source.—Dealing first with *surface supplies,* that is those taken direct from rivers or from subsoil collecting chambers, the design of pumping plant has been carried to a very advanced stage of perfection. In such cases the circumstances are favourable, in that the plant is altogether on the surface and can be designed in the most compact form, with any elaboration of valves or fittings which may secure economy in working.

A typical example of this is the Worthington High-duty Pumping Engine, shown in *Plate* I. This you will see, is direct acting, without any flywheel or rotary motion whatever. The cylinders are arranged for triple expansion and the valves are operated from the crosshead. A very important element in the design of direct steam driven pumps is the adjustment of the work done in the steam cylinder to that required in the pump. As you know, the pressure in the steam cylinder gives a diagram somewhat in the form of a boot, whereas a similar diagram taken from the pump barrel shows a simple rectangle. It is clear therefore that in dispensing with a flywheel or other heavy moving weight, in which the surplus power at the early part of the stroke is stored up to be returned at the latter part of the stroke as the steam pressure falls, some means must be adopted for counteracting the relative variation in the steam and water pressures which occurs during the length of each stroke. In the Worthington pump as illustrated this is effected by separate plungers working in cylinders connected with the rising main. These cylinders are arranged to oscillate on trunnions in such a manner that, as the steam pressure in the cylinder falls, the water pressure on this plunger comes into operation to assist the steam piston in its forward movement, and *vice versâ*.

There are many other devices for effecting the same object, but to describe them here would unduly prolong my paper; and, as the direct acting pump is generally used in connection with very large installations, such as are not likely to come within the scope of your military practice, I will not now go further in referring to them.

Dealing now with *underground sources of supply*, the question of pump design becomes at once more intricate, but at the same time more interesting. Any attempt to secure high "duties" similar to those obtained with the Worthington class of surface pumps must be abandoned, and special attention must be directed to the design of the buckets, valves and headgear.

Well Pumps.

I have already pointed out that a well permits of the use of double or triple pumps in which the rods are automatically balanced one against the other, and that if fixed above "the rest level" of the water such pumps may be examined and the valves repaired or renewed *in situ*. *Fig.* 1, *Plate* II., illustrates a pump of this class, the details of which were designed by myself. You will see that it is a "triple" pump, fitted with plungers working through stuffing boxes. These plungers have a sectional area equal to one half the area of the pump buckets, and the water is thus delivered in six instalments per revolution, which produces a practically continuous stream without any jar due to the reciprocating motion of the buckets. Covers are provided which enable the buckets, the bottom or suction valves and the delivery valve to be removed without disturbing any other part of the pump.

I should like here to warn you against the misuse of the word "double-acting" in connection with a bucket and plunger pump such as this. Although water is delivered in equal quantities on both up and down strokes, the pump is *not* double acting. This term is only correctly applied to pumps which deliver the contents of the barrel *twice in every revolution*, which you will see this pump does not do.

The bucket and plunger pump, as this is commonly called, is not suitable for working at any great depth from the surface, owing to the fact that the rods are put in compression on the down stroke. In such cases, the plungers should be omitted, to secure the rods being always in tension, and an air vessel should be fixed on the rising main as close to the pump as possible.

In the case I have illustrated the well was supplied with water from a boring driven through the bottom, and this boring was fitted with a valve operated from the surface by means of a rod and gearing. The well could therefore be emptied below the level of the pumps at any time by shutting this valve and pumping the water out. In cases where this arrangement cannot be carried into effect, some means must be provided for giving access to the working parts of the pump; and this is done by extending the pump barrel upwards by a pipe of slightly larger diameter and fixing the stuffing box and delivery valve on the top of the same, above the rest level of the water. This does not however enable any repairs to be effected in the buckets or suction valves *in situ;* and as these have to be lifted up through the "sleeve" or barrel extension whenever they require repair or renewal, this type of pump does not offer any advantages over the borehole pump, which I will now describe and illustrate.

Borehole Pumps.

The use of borehole pumps as permanent plant is a comparatively modern practice; but, as the cost of a boring is only from one-third to one-fifth that of a well and it can be constructed in a much shorter time a great economy of initial outlay and a great saving of time can be effected where the required supply can be obtained from a boring. If the quantity of water required does not exceed 10,000 gallons per hour, borings will generally yield the desired amount without difficulty, and within a reasonable depth from the surface.

The pump shewn in *Fig.* 2, *Plate* II., is, I believe the largest of its kind ever made. The boring also is the largest ever sunk for waterworks purposes in this country, being 1,515 feet deep, 2 ft. 6 inches diameter for a depth of 300 feet, and terminating 15½ inches in diameter at the bottom. The pump is suspended in the 2 ft. 6 inch tubes at a depth of 300 feet, and is supported partly on the 18 inch bore tubes which commence at this level, and partly on the top of the 2 feet 6 inch tubes. The barrel is 19 inches internal diameter and the stroke 3 feet, but you will observe that, by arranging two pump buckets, one above the other, the pump is made double-acting. The objection to this design is that double rods have to be provided (in this case a solid rod working inside a hollow tubular rod), and in lifting the buckets to the surface both rods must be lifted together and the couplings removed alternately. This doubles the labour of lifting the buckets as compared with the single-bucket pump, but in practice I have not found this objection to be a serious one. A 30-ton travelling crane is erected over the machinery and the buckets have been removed, repaired and replaced within a period of five days. The chief novelty in this pump however is the form of the buckets and their valves. Instead of the ordinary short buckets with heavy single valves you will see that these are long cylinders fitted with a number of small rubber disc-valves, those in the lower bucket opening inwards and those in the upper bucket outwards. The inner or adjacent ends of the buckets fit into and work in the pump barrel, being provided with circular grooves instead of the ordinary spring rings or leather packing. To secure an ample passage for the water entering the lower and leaving the upper bucket, the pump itself is enlarged in diameter above and below the working barrel. It may interest you to know that this is the first pump constructed of this design, and that the working results have proved highly satisfactory. The pumping level of the water is 300 feet below surface level and the conditions of working are therefore extremely severe. By means of this design the minimum water way through the buckets is 60 per cent. of the bucket area and this only applies to one point of the bucket, a result which would have been impossible with any other form of pump-valve. The yield of the boring is 32,000 gallons per hour or over ¾ of a million gallons in 24 hours, but the full capacity of the pump is 50,000 gallons per hour or 1,200,000 gallons per 24 hours.

My next illustration (*Fig.* 3, *Plate* II.) is a pump which has not yet been subjected to a practical test, but which I have every reason to believe will prove very successful when put into regular work. In this case the boring is of much smaller diameter (viz. 13½ inches external diameter of tubes) at pump level, and, owing to the restriction of the access of the water to the boring, it is necessary to fix the pump barrel at a depth of 340 feet from the surface to allow for a possible fall in the water level of 210 feet below rest level. The difficulties of design were in this case far more serious than in the former case, and involved careful study and many intricate calculations.

Owing to its great depth, it was desirable to make it single-acting and the maximum internal diameter that could be adopted was

9½ inches. You will observe that the small disc valves have been adopted for the suction valve, but the small diameter of the boring prevented their adoption for the bucket valve. The bucket is of the extended form, so that the valve does not work in the barrel but always delivers into the rising main, which, being 1 inch larger in diameter than the barrel, affords a larger area for the passage of the water. The most unique and interesting point of design in this pump is, however, the pump rod, which is formed of tubes 7½ ins. external diameter and therefore acts as a plunger, the object being to facilitate the balancing of such an unusual length of rods.

As the question of balancing a single-acting borehole pump is extremely complex, and at the same time very interesting, I propose to make as clear as possible some of the principal points involved in it. You will of course realise that such a pump *unbalanced* involves the lifting, on the upstroke, not only of the water but of the rods, bucket, etc.; while on the downstroke the weight of the rods, bucket, etc., acts with the stroke and tends to pull the engine forward. Now if the pump is operated by a direct-acting steam cylinder without gearing, you will understand that it is possible, by a proper adjustment of the steam valves, to store up the work done by the rods, etc., in descending and utilize it in lifting them on the up stroke. The operation is as follows:—The boiler steam is admitted to one side only of the piston during the up stroke of the pump; it is then cut off altogether, and the steam in the cylinder is allowed to pass from one side of the piston to the other for a portion of the down stroke; but at the proper point this communication is cut off, so that a portion of the steam is retained behind the piston and, in being compressed, stores up energy which is added to that of the incoming boiler steam for use on the next up stroke of the pump. This operation is of course the same as takes place in the old fashioned "Bull Engines." *Fig.* 4, *Plate* II., shows a pump of this kind, which I have used for the purpose of obtaining a temporary supply from a borehole pending the construction of more economical permanent pumping plant. The main object in this case was to have a pump which could be quickly fixed and readily removed, and which would take up a very small ground space beyond the boring itself so that the buildings and foundations of the permanent plant could be carried out without disturbing the temporary pump.

To return to the question of balancing pump rods. The application of the direct-acting pumping engine is, for reasons of economy on the one hand and convenience on the other, confined to very large pumps and small temporary plants such as that I have illustrated. For small installations it is more satisfactory to use gearing between engine and pump. In the first place this greatly reduces the size of engine required ; and secondly the loss of power by friction in the gearing is compensated for by reduced initial cost, greater economy and smoother running. Where gearing is used, the speed of working can be varied within much wider limits, an important matter in cases where the actual yield of the borehole has not previously been ascertained.

In a single-acting geared pump you will see that the dead weight of the bucket and rods must be balanced by an equivalent weight attached either to the " tail " (or outer end) of a rocking lever or to a chain or rope working over a pulley. So far the problem is a simple one, but to secure equal strains on the driving gear on both the up and down strokes of the pump, means must also be adopted for distributing the work of *lifting the water* (which only operates during the up stroke) so that the effect on the engine is equal on both strokes. At this point the problem becomes somewhat more confusing, and I must ask your careful attention while I endeavour to make clear the calculations involved in determining the amount of balance weight required in any given case. It is important to note that the weight of the rods must be calculated as immersed in water if solid, but as in air, if hollow. This weight is constant and easily ascertained, but it must be remembered that it *operates downwards on both strokes.* The weight of the water in the pump, however, only affects the bucket on the up stroke, as on the down stroke this weight is borne entirely on the suction or bottom valve. The balance weight must therefore include one half of the pressure of water on the bucket in addition to the weight of the rods. There is another element of variation in the weight of the water acting on the bucket, which not only operates differently on the up and down strokes but which varies as the water in the boring falls from "rest level" to "pumping level." This is the upward pressure on the bucket due to the "suction head" or height of water outside the pump, and from *Fig.* 1, *Plate* III., you will see that this is only effective during the up stroke, when the suction valve is open and the bucket valve closed.

I have previously mentioned that, in the case of the special pump illustrated in *Fig.* 3, *Plate* II., the difference between " rest level " and " pumping level " is expected to be 210 feet; and you will be able now to appreciate what the effect of this great variation will be upon the equal working of the pump. Now if there were no fall in the level of the water when pumping was in operation, the work on the up and down strokes could be equalised by a fixed balance weight, but the variation due to the fall of the water-level in the boring can only be adjusted by a *movable balance weight*, the position of which can be altered according to the level of the water in the boring. Thus at starting (water at "rest-level") this weight will be on the pump end of the rocking lever, and at lowest pumping level the weight will be at the opposite end of the lever. Here it is interesting to note that by arranging for the moving balance to travel the whole length of the rocking lever instead of from the fulcrum to one end only, the actual moving weight required is one half what it would otherwise be.

As I cannot devote more time to further explanation of this rather intricate point, I will give you formulæ from which the amount of balance weight, both moving and fixed, may be calculated in the case of a bucket and plunger pump of the type shewn in *Fig.* 3, *Plate* II.

$$\left.\begin{array}{l} x = \text{pressure per square inch due to head of water inside pump.} \\ y = \text{pressure per square inch due to head of water in outside} \\ \qquad \text{pump.} \\ \mathrm{W} = \text{weight of rods and bucket (rods in air, bucket immersed).} \\ \mathrm{B} = \text{balance weight (at same distance from fulcrum as pump).} \end{array}\right\} \text{lbs.}$$

$$\left.\begin{array}{l} \mathrm{A} = \text{area of bucket} \\ a = \text{area of plunger} \end{array}\right\} \text{in square inches.}$$

Water at Rest Level.

$$\mathrm{B} = \mathrm{W} - xa + \frac{\mathrm{A}\ (x - y)}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1).$$

(or, if $\mathrm{A} = 2a$, then $\mathrm{B} = \mathrm{W} - ya$).

Water at Pumping Level.

$$\mathrm{B} = \mathrm{W} - xa + \frac{y\mathrm{A}}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2).$$

(or, if $\mathrm{A} = 2a$, then $\mathrm{B} = \mathrm{W}$).

Moving weight is $\dfrac{(2) - (1)}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3).$

Fixed weight is $(2) - (3)$.

Mr. Ashley (the patentee of the multiple pump valves I have already described) has patented a very simple method of automatically adjusting the balance weight according to the level of the water in the boring. This is done by providing a communication pipe to admit the water outside the pump to the interior of the hollow rods. In this case the *internal* area of the rods must be one half the area of the pump bucket. Water of course stands inside these rods at the same level as the water in the borehole, and falls as that falls. The operation of the patent is too complicated to explain here, but I have satisfied myself that it is absolutely automatic and it has the great advantage of dispensing with the moving balance weight. The one disadvantage is the communication pipe admitting water to the inside of the rods. This has to pass through both the bucket and the suction valve, and necessitates a stuffing-box at the bottom of pump, where the pressure of water is always at the maximum, and the risk of leakage or "slip" is proportionately great. The pump I have illustrated is designed with hollow rods of the required diameter, and if any means can be adopted to obviate this objection I may ultimately adopt this patent balance in preference to a moving weight.*

Although I have not attempted to deal with every class of pump, I trust these illustrations taken from my own practice will prove interesting and useful as representing modern practice applied to special conditions. I will now direct your attention to a few practical points connected with the calculations for ascertaining the duty of various types of pump.

Calculation of "Duty."

The standard adopted by the pioneers in the manufacture of pumps was the foot pounds of work done in the pump divided by the coal consumed in cwts. This however involved the duty of the boiler as well as that of the engine and pump; and, as it is usually very easy to arrive at the boiler efficiency separately and this element in the calculation has no bearing upon the design of the engine and pumps, I think it is more convenient to divide the foot pounds of work done in the pump by the weight of steam used in the engine. As an evaporation of 8·93 lbs. of water per lb. of coal (a fair average in ordinary practice) represents 1,000 lb. of steam per cwt. of coal, the results will be readily comparable with the older standard, as they will be "thousands" in the former case and

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* NOTE.—Since the above was written the patentee has designed an arrangement by which this difficulty is satisfactorily overcome, and the system has therefore been adopted in the case referred to.—P.G.

"millions" in the latter. The foot pounds of work done in the pump are very simply ascertained by multiplying the number of gallons lifted by 10 and the result by the head in feet under which the pump is working. In a borehole pump the head is of course the difference between pumping level and discharge level plus an allowance for friction where the water-way is restricted. For surface pumps a pressure gauge on the delivery main will give the actual head, including any friction in the rising main. The steam used may be ascertained by measuring or weighing the water discharged from the air pump and adding the water collected in the steam jackets, cylinder-drains, etc., which is usually discharged through an automatic steam trap. Steam condensed in a long steam pipe between boiler and engine should not be included, as it bears no relation to the efficiency of the engine.

An alternative method of expressing the efficiency of a pumping engine is to state the proportion or percentage which the Pump Horse Power of the Engine bears to the Indicated Horse Power. The latter is calculated from diagrams taken from the cylinders at frequent intervals, and the former by dividing the foot pounds of water lifted per minute by 33,000. The objection to this method is the risk of error in reading from a large number of indicator diagrams, and the great variation in the proportions between the Indicated Horse Power and the steam consumption under different conditions of working.

To give you an idea of the results to be expected with different types of pumps the following Table shows a fair average obtained in ordinary practice.

	Foot lbs. water lifted per 1 lb. steam used in engine.
1. High duty surface pump (Worthington type) triple expansion, surface condensing (106,500 galls. per hour)	162,000
2. Borehole pumps with force pumps on surface, direct-acting, non rotary compound condensing engine (50,000 galls. per hour)	120,000
3. Compound condensing engine geared to borehole pumps, with direct-acting force pumps (32,000 galls. per hour)	95,000
4. Small non-condensing engine geared to three-throw well pumps (10,000 gallons per hour)	50,000

(6). Capital Outlay and Cost of Maintenance.

Let me now call your attention to the relation between capital outlay, cost of working and cost of repairs and maintenance with different types of pumps and engines.

In practice you will find that, for any particular conditions, the most suitable type of pump will be governed by the position in which it has to work. Thus for single boreholes, the choice lies between the single acting or "concertina" (double acting) pump; this again being determined by the diameter of the boring and the depth at which it has to be fixed. For deep wells the double pump (that is two single-acting pumps side by side) is most suitable; for shallow wells a double or triple pump with plungers is very convenient: while for surface pumps, or in the case of large diameter shallow wells, the double-acting single plunger pump or single-acting triple plunger pump would be most satisfactory. Questions of relative economy and cost do not therefore seriously affect the selection of the pump itself.

In deciding upon the motive power and method of connecting the pumps thereto, there is a good deal more scope for variation. In selecting the type of engine, local circumstances must be carefully considered. Thus where fuel is abundant and cheap the steam engine will secure greater economy than any other form of motive power; and it should be borne in mind that with cheap fuel it is not desirable to incur much extra expense or complication of apparatus in order to effect a trifling economy of fuel consumption. The use of direct-acting (either rotary or non-rotary) engines for pumping involves the use of very large engines, and the extra capital outlay must be set off against the saving effected by dispensing with gearing. Non-rotary (direct-acting) engines involve considerable complication of the valve gear and a tendency to run at short-stroke, after some wear has taken place in the cylinder; the slightest disarrangement of the valve gear is also liable to cause a serious accident. All complications of design involve not only extra capital outlay but increased cost of repair maintenance and supervision, and these should be carefully considered in estimating the net economy to be effected by them.

As regards internal combustion engines, these have the advantage of saving the capital outlay on boilers and greatly reducing the cost of attendance, but they involve the use of gearing or belting (or preferably a combination of both) owing to the necessity for running them at high speeds. They are best suited for small installations, where ordinary fuel is expensive (*e.g.* where coal exceeds 20/- per ton) and where it is desired to limit the amount of labour and attendance to a minimum. If coal gas is not available, or cannot be obtained at less than 4/- per 1,000 cub. ft., "Dowson" or similar gas-making plant may be used, but of course this means as much capital outlay and attendance as would be involved by boilers; under such circumstances therefore the use of an oil engine should be considered. Where gas is cheap, and taking oil at prices now current, I do not think there is much difference in the working cost of gas and oil engines; the latter involve some complication of the engine fittings and some extra risk of failure, so that probably the former would be preferable. Oil engines are however very convenient in isolated stations and for small pumps; they can be adjusted on starting so that they will stop automatically at any given time, and in such cases the only attendance required is for an hour or less every morning.

Small surface pumps, combined with oil engines fixed to the same bed plate, would be useful for military purposes on account of their portability, if oil can be carried in sufficient quantity or obtained from local sources. For extended marches in districts where oil cannot be readily obtained they are of course useless; neither are they suitable for pumping water from underground sources. Speaking generally, I believe the portable steam engine, with locomotive and power gear interchangeable, is the most convenient for military purposes. It is simple in construction, will stand a good deal of rough travelling, is easily fixed, moved, worked and repaired. Fuel of some kind is almost universally obtainable; and the necessity for water is one which the machine shares with its employer, and which is not therefore likely to cause any difficulty.

PART II.—AIR-LIFT SYSTEM.

I will now turn to the more fascinating aspect of my subject, viz., the application of compressed air to raising water from underground sources.

Description of Plant.

The plant required for this purpose is illustrated on *Fig.* 2, *Plate* III., and you will at once be struck by its simplicity. The only part in motion is an air compressor, which can be operated from any motive power that may be most convenient, whether fixed steam engine driving direct as shewn, portable steam engine, or gas or oil engine driving by means of belts or gearing. The compressor itself is a simple machine, with nothing specially elaborate or intricate in its design, and quite as portable as any type of engine likely to be used in connection with it. All the rest of the plant is stationary, having no moving parts or valves whatever. From the compressor the air is conveyed to a wrought iron or steel cylinder (called the receiver), which is designed of strength sufficient to stand an internal pressure equal to the maximum head of water against which the plant is likely to work. Thence the air is conveyed down the well or boring to a depth usually calculated as twice the depth of the "pumping level" of the water below the surface. The water pipe is also suspended in the well or boring and may have the air pipe inside or outside it as preferred, but the air should in either case be discharged some few feet above the bottom of the water main. The air pipe terminates at this point in a nozzle, the purpose of which is to distribute the air in as fine a state of subdivision as is possible, the efficiency of the plant depending upon the equal diffusion of the air into the body or bulk of the water column.

The only theory connected with the operation of this plant which is generally accepted as beyond dispute is that the mixture of air and water in the water main renders it lighter than the external column of water alone. Thus as soon as air begins to mingle generally with the enclosed column of water, the larger weight of the external column of water produces an upward movement of the internal column, and when this reaches the point of discharge, the water commences to overflow the water pipe, the enclosed air separating naturally from the water.

This operation is so simple in its character that, at first sight, one would not anticipate any difficulty in applying it practically to almost any reasonable conditions. As however is very generally the case, that which is so extremely simple at first view proves on closer investigation to involve unexpected complications at every point, and most of those who have had practical experience of this very fascinating system have had cause to regret that so little is really known of the natural laws which govern its operation or of the results which may be expected under varying conditions. The system has only been recently introduced into this country; and although it has been known and used in America and on the Continent for a longer period, it has not yet been investigated sufficiently to arrive at any definite data as to the relative dimensions or general capacity required to produce any desired result under any given conditions.* The many failures which have attended its use in this country, as well as the very obvious advantages of the system, have together created an unusual amount of interest among water engineers and those using water from underground sources. In the present state of our knowledge however, it would be a useless pretence on my part to attempt to analyse or explain the laws which govern the practical application of the system to varying circumstances.

On points of theory I can only say that, in my own opinion, the success and efficiency of the system depends largely upon the equal and minute distribution of the air in the body of the water; this again depends upon the form of the air nozzle, and the form should be varied according to the head of water to be lifted. That the air pipe should be large enough to carry the required volume of air without producing appreciable friction, and that the compression of the air should be effected in the most economical manner are of course obvious; but the quantity of air required per unit of water lifted is at the present time largely a matter of guess-work, and I believe rarely justifies in practice any previous estimate based upon theory. It is consequently a matter of the utmost difficulty to calculate or design the capacity and proportions of any plant to best suit any given conditions of working. Until experimental research has settled this point at least, it is clear that the use of the system in any given case must be considered an experiment and nothing else, and the more general use of the plant cannot be recommended.

Limitations.

I need not explain that for lifting water from surface sources the apparatus commonly known as the "Air-lift Plant" is not applicable, although it would be possible to use compressed air in an ordinary injector (such as is used for boiler fuel) where the lift was not too great. This point may perhaps be important in considering the question of equipping military engineer units with compressor plants. It is clear that it would be very important that any plant for raising water should be available whether the source of supply were underground or at surface level. However I propose to deal particularly with the use of compressed air for lifting water from wells and borings.

Let me now deal with the question of efficiency. From what I have just said it will be clear that any attempt to define the general efficiency of the Air Lift Plant, as compared to that of the more familiar pump, is out of the question. The utmost that can be said is to record the best results obtained in practice. These point to a figure approximately between 30,000 and 40,000 ft. pounds of water lifted per lb. of steam used ; but this could not be expected unless the conditions were extremely favourable, especially in regard to the total lift of the water, which, when it exceeds 80 or 100 ft., is a serious obstacle to efficiency. Thus it must be assumed that unless other factors than economy of working enter into consideration, the Air Lift Plant should be discarded without a moment's hesitation. This much I believe would be admitted readily by its most enthusiastic advocate.

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* Since this Paper was written, some very elaborate tests have been made with a large Air-Lift plant at Birkenhead, see *Transactions of British Association of Waterworks Engineers, Vol. IX.* (1904).

Having said enough to deter anyone from entering rashly upon an application of the system regardless of circumstances, let me call your attention to certain conditions to which the Air Lift Plant is peculiarly well adapted, in spite of its want of efficiency and the uncertainty as to the results to be expected.

Utility.

In searching for underground sources of water supply it is a common practice to sink a preliminary or trial boring of small diameter to determine the sequence of the strata, the rest level of the water (if any) and the probable yield. The last item depends very largely upon the porosity of the water-bearing beds. Although other circumstances may occur to affect the yield of a boring, it may be generally assumed that the depth at which the pump is fixed will prove a relative indication of the quantity of water to be obtained ; and as it is very desirable to ascertain by experiment the depth at which the required supply can be obtained before fixing a permanent pump in the boring, the ease and rapidity with which an air lift plant can be installed and removed render it particularly suitable for such a purpose, especially where the boring is too small to admit of a test with the ordinary form of pump.

Of course even in such cases the limitations of the system must be borne in mind, the most important being the fact that the air nozzle must in all cases be *immersed* to a depth not less than the height to which the water has to be lifted. It is therefore impossible to lower the water level more than one half the total depth of the boring or well ; and although a scale may be obtained, shewing the proportionate rate of increase in the yield at various depths from surface, it is not possible with the Air Lift Plant to ascertain the effect of pumping *from the bottom* of any well or boring.

The system is not, however, limited in practical value to experimental or temporary purposes only. There are conditions under which it may be very successfully adopted for permanent use. Mr. Maxwell, the Borough Engineer of Tunbridge Wells, has an Air Lift Plant in constant use delivering from 20,000 to 30,000 gallons per hour from a depth of between 100 ft. and 160 ft. below the surface; and although I should not myself recommend its adoption for quantities exceeding 10,000 gallons per hour or for lifts exceeding 100 ft., the case I have mentioned affords an excellent example of special conditions which fully justified the adoption of the system. Here two new borings were situated some distance from the previously existing works, and the use of the ordinary type of plant would have necessitated the erection of separate and additional boilers, engines, pumps, foundations and buildings, as well as the establishment and labour charges incidental to an independent pumping station. The compressors were erected adjacent to existing buildings; and as the existing boiler power proved sufficient to drive them, the expense of a new pumping station was entirely avoided and the extra cost of working, due to the inferior efficiency of the plant, was more than covered by the reduction of capital and maintenance charges.

There are many cases where the cheapest and most effective method of obtaining any desired quantity of water is by driving a number of borings at considerable distances apart. The suitability of an air lift installation under such circumstances will, I think, be apparent. A central compressor station would provide all the moving machinery required; air pipes could be laid underground to each of the borings, and the discharge therefrom either be conveyed to force pumps erected at the compressor station or carried direct to a service reservoir supplying the district.

For dealing with sandy waters the absence of valves in this plant gives it a great advantage. Also where the water is derived from ironstone beds, the aëration secured by this system is of great value, such aëration being the most effective means of precipitating any iron dissolved or suspended in the water.

The advantages of this system which will I think most appeal to Military Engineers, are those of simplicity, ease and quickness of erection and removal, and portability.

To enable me to deal with the application of the air lift system to Military field work, the Commandant S.M.E. has kindly furnished me with figures giving the maximum and minimum supplies of water required by the ordinary unit in the field, whether on active service or engaged in manœuvres. The unit is given as one Infantry Division, the requirements of a temporary camp work out at about 26,000 galls. per day, and for standing camps at about 80,000 gallons per day. Assuming pumping is continued for 12 hours in every 24, the rate of pumping will be about 2,200 gallons per hour in the one case and 6,700 gallons per hour in the other. Messrs. Le Grand and Sutcliff have very kindly supplied me with a design (*Plate* IV.) for a portable compressor driven by an oil engine, which will prove of special interest to military engineers; the following data will also be useful,—

	Case 1. (3,000 gallons per hour) lifted 100 ft.	Case 2. (8,000 gallons per hour) lifted 100 ft.
Approx. Weight of Compressor and Engine	60 cwt.	150 cwt.
,, Cost ,, ,, ,, ,,	£250	£400

The special application of the System to military purposes is however such an important matter, and one upon which I am so incompetent to enlarge, that I can only suggest the desirability of further investigation. There can be no doubt that many of the conditions met with, both in active service and in ordinary field work, are particularly favorable to the use of the Air Lift System; and I would recommend a careful study of the subject with a view to ascertaining the conditions under which the System could be effectively applied and the design of plant which would best answer the special requirements of the case.

LIST OF PLATES.

	FIG.	PLATE.
Worthington Triple-Expansion High-Duty Pumping Engine		I.
Three-throw Bucket and Plunger Pump	1	II.
Double-acting Borehole Pump	2	,,
Single-acting ditto	3	,,
Direct-acting Steam-driven ditto	4	,,
Section of Well, showing Pump with Rest and Pumping Levels of Water	1	III.
Section of Borehole with Air-Lift	2	,,
Portable Air Compressor with Oil Engine		IV.

LE EXPANSION
NGINE.

PLATE I.

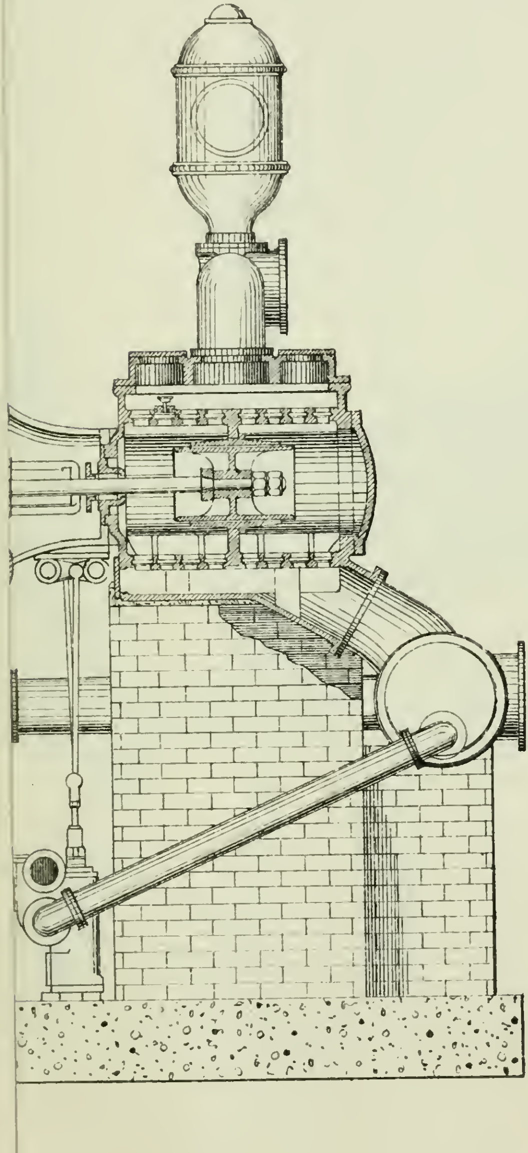


PLATE I.

SECTION OF WORTHINGTON TRIPLE EXPANSION HIGH DUTY PUMPING ENGINE.

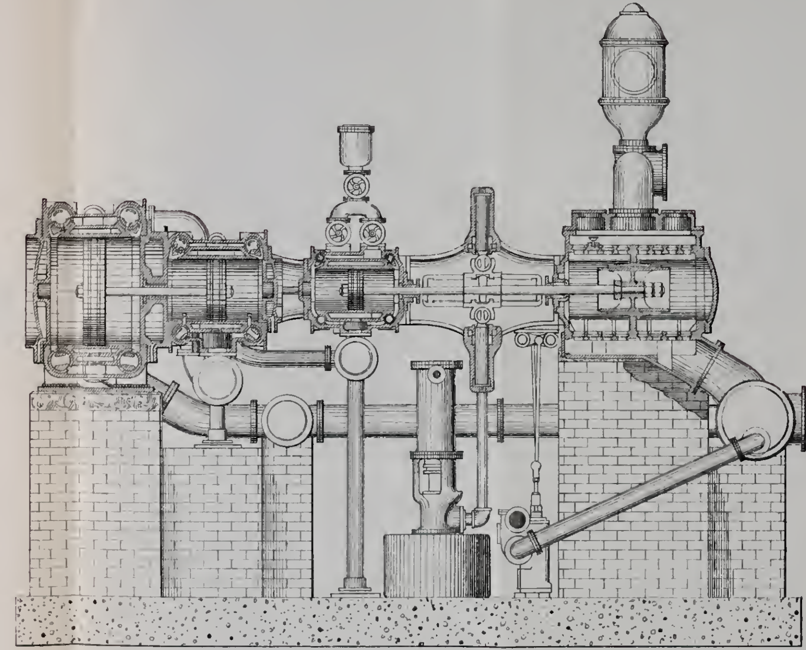
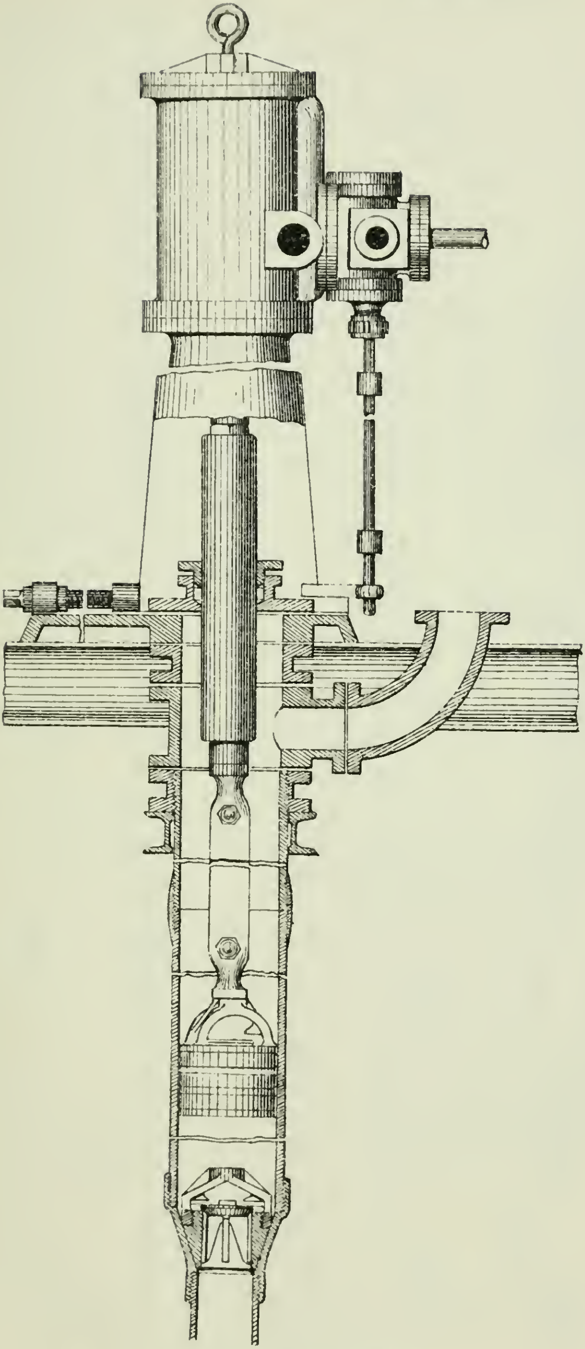


PLATE II.



INGLE ACTING
LE PUMP.
MSFORD)

Fig. 4. DIRECT ACTING STEAM
DRIVEN BOREHOLE PUMP.

PLATE II.

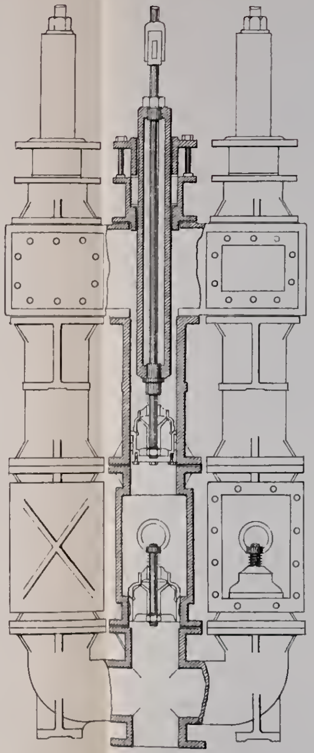


Fig: 1.
3 THROW BUCKET AND
PLUNGER PUMPS.
(HALSTEAD, ESSEX)

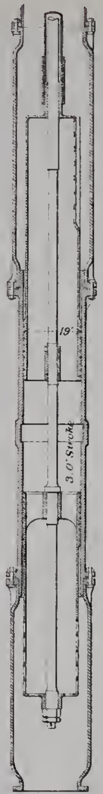


Fig. 2. DOUBLE ACTING
BOREHOLE PUMP.
(GAINSBOROUGH)

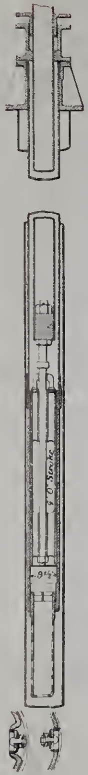


Fig. 3. SINGLE ACTING
BOREHOLE PUMP.
(CHELMSFORD)

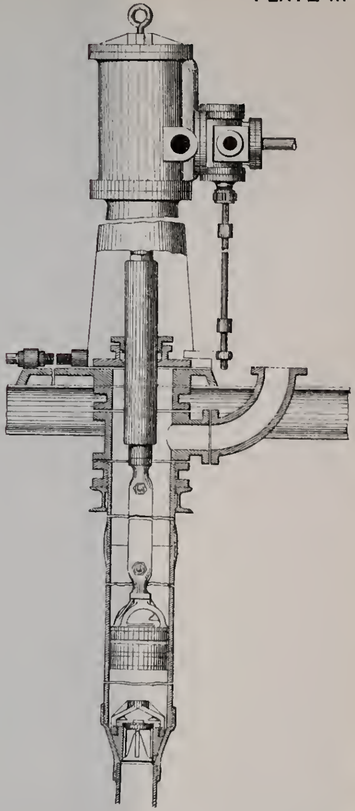
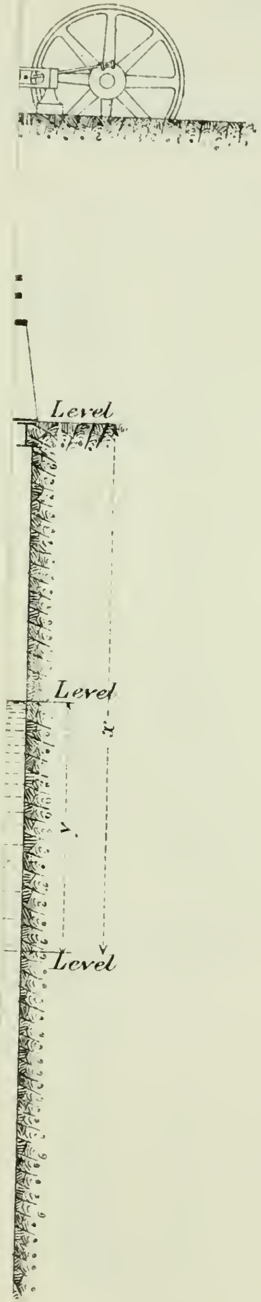


Fig. 4. DIRECT ACTING STEAM
DRIVEN BOREHOLE PUMP.



ON OF WELL SHOWING
& REST AND PUMPING
S OF WATER.

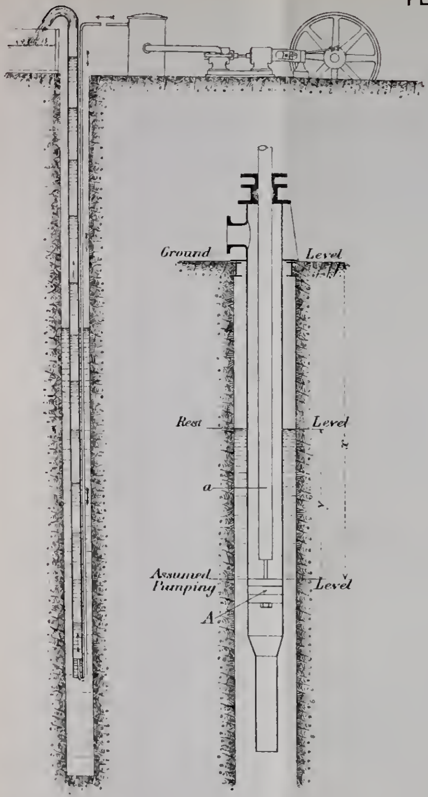
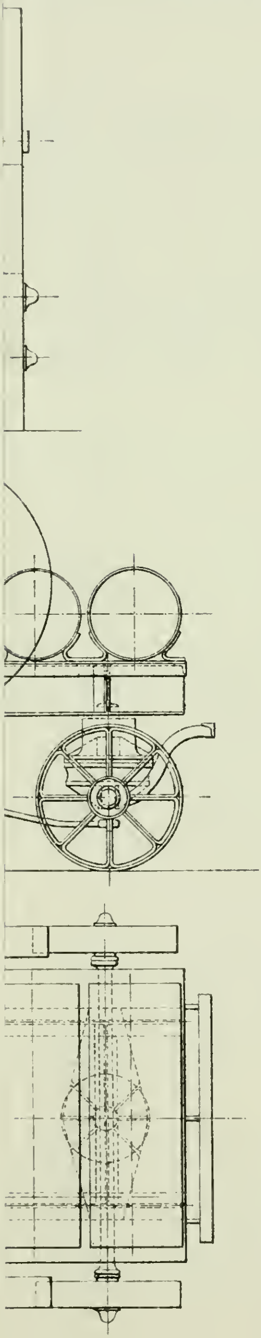


Fig. 2.
SECTION OF BOREHOLE WITH AIR-LIFT.

Fig. 1. SECTION OF WELL SHOWING PUMP & REST AND PUMPING LEVELS OF WATER.

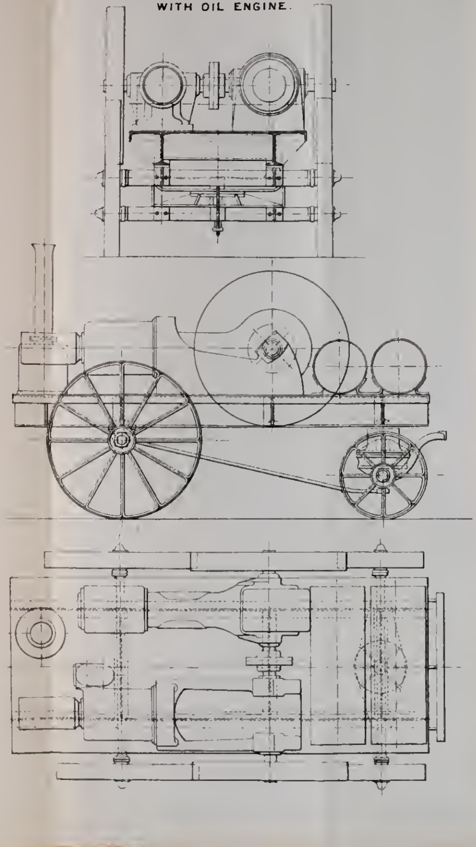
SOR PLATE IV.



PORTABLE AIR COMPRESSOR

PLATE IV.

WITH OIL ENGINE.



PAPER V.

THE PROTECTION OF FORESHORES.

BY

W. H. WHEELER, M. Inst. C.E.

(*Lecture delivered at the School of Military Engineering, Chatham, on February 4th*, 1904).

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NOTE.—For full information the reader is referred to Mr. Wheeler's "*The Sea Coast.*"—[ED.].

THE PROTECTION OF FORESHORES.

NECESSITY FOR PROTECTION.

THE destruction that is going on all round the coast of this country has recently attracted more than usual notice; and the attention of the public is being frequently directed to the washing away of our shores and to the need for carrying out some organised means of protection.

Erosion and destruction of cliffs and waste of land is in progress more or less on all the coasts. The devastation has, however, been greatest on the cliffs of the east coast, which consist to a very large extent of glacial drift. In the bay between Flamborough Head and the Humber, where the cliffs are exposed to the full force of north-easterly gales with a fetch of open sea of 400 miles, it has been calculated that for many years the average loss of land has been at the rate of 2½ yards a year; and that a width of two miles has been washed into the sea since the Norman Conquest. Along this part of the coast sites once occupied by villages and townships are covered several fathoms deep in the sea, and the only record that exists of their former existence is a note on the map—"washed away by the sea." The townships of Wilsthorpe, Auburn, Hartburn, Withon and Cleton are all buried in the ocean; while other parishes, such as Monke White, have lost their churches and houses and the greater part of their land. Kilnsea church fell about 70 years ago and the village had to be removed. The ruins of Aldborough church are far out at sea, and Thorpe has lost three-fourths of its land. Of Ravensur, once a seaport town at the mouth of the Humber, not a vestige is left.

There is a record of a Roman settlement off the coast of Norfolk near Cromer, the site of which is now buried in the ocean. When Doomsday book was compiled Cromer was an inland hamlet and part of the old parish of Shipden, a place at one time of considerable importance. Nearly the whole of this parish has disappeared, the ruins of the church being half a mile out at sea, and there is a local tradition that on stormy nights fishermen may hear its bells ringing beneath the water. South of Cromer the cliffs are wasting rapidly and recently part of the golf links disappeared, and between these and Mundesley during the last half century the cliffs have been washing away at an average rate of 14 feet a year.

Dunwich in the time of the Saxons was a flourishing town and port and the seat of Government of the King of the East Angles; at one time it was the centre of a bishopric and the site of six churches, and even up to the time of Edward I. it was of sufficient importance to maintain several ships of war for the King. But it has almost entirely disappeared; the last of the six churches now stands a solitary ruin, close to the edge of the cliff, and will soon follow the others into the sea, and the present village consists only of a few scattered houses on the hillside.

In the mouth of the Thames, at Reculvers, the sea has so far encroached on the land that the church, which at one time stood on the cliff a mile from the sea, had to be moved inland, the village and churchyard being washed away. The two towers of the ancient church, now used as a sea mark, have only been preserved by works executed on the foreshore for their protection. In the Isle of Sheppey the cliffs are continually falling, and the site of Warden Church, with the churchyard and some houses, has entirely gone, the church itself having been removed inland.

Amidst all this narrative of waste and destruction, denoting the slow and gradual disappearance of this country beneath the sea, it may be some poor consolation to be told that, at the present rate of erosion and under present physical conditions, it will take five million years before the whole of the land that constitutes England will be buried beneath the waters of the sea; and that there will then only remain a few islands, of the harder rocks, standing above the water, from which the last natives will be able to gaze on the site of another Atlantis buried in the ocean.

All attempts to preserve the littoral parts of a country from destruction must be a perpetual struggle against natural causes. The erosion of the cliffs is only a part of that system of Nature under which continual destruction and reconstruction are taking place. All land above the level of the sea is being continually worn away by means of waves and tides during gales, aided by the action of rain and frost on the surface, the finer particles of the eroded material being carried away in suspension by the tides and ultimately deposited on the bed of the sea, there to form the sedimentary rocks of the long distant future.

Until the last few years very little attention was paid to the wasting of the coast, the landowners, who were principally concerned, accepting the loss of their land as an inevitable consequence of its bordering on the sea.

But the increasing growth and density of the population, especially in the large towns, has led to the establishment of numerous health and pleasure resorts on the sea side; and places, formerly only known as small villages, have merged into towns requiring promenades and sea walls and the protection of the shore from the encroachments of the sea.

The construction of the sea walls required for this purpose has frequently been entrusted to that maid-of-all-work a Town Surveyor, who had no special knowledge of the action of waves on sea walls and beaches or of the laws governing the transport of beach material. The works carried out have consequently in many cases become failures, and very large sums of money have been wasted owing to the want of proper appreciation of the forces that have to be contended with.

The numerous ruins of sea walls and shore defences that are to be found all round the coast testify to the necessity of those in charge of such works having experience and knowledge, not only of the forces that have to be contended with but of the local conditions that have also to be taken into account.

To the Military Engineer this subject is of interest, as foundations of forts and other defensive works erected on the shore are subject to be undermined by the action of the waves in denuding the beach. From time to time the War Office has had to call in experts to advise as to the works necessary for the preservation of such buildings as the Redoubts at Sandgate and Eastbourne, Landguard Fort at Harwich and Sandown Castle near Deal.

The wasting away of the foreshore in the estuary of the Thames and Medway has from time to time been a source of trouble to the War Department; and under the direction of officers of the Royal Engineers groynes, and other works of shore defence, have had to be carried out for the protection of the Forts at Garrison Point and the Isle of Grain and along the frontage of the Royal Dockyard at Sheerness.

Factors to be Considered in Coast Protection.

For the protection of the coast the chief factors that have to be taken into consideration are

(1). The action of the waves breaking on the shore, aided by the tides.

(2). The movement of shingle and beach material along the shore, and the possibility of accumulating this by means of groynes in front of the particular part of the coast to be protected.

The sea shore of this country may be divided into two general classes, the features of which are familiar to everyone who has been at the seaside; the one where the sea is margined by cliffs, at the foot of which the beach is banked up with shingle; and the other where a long low flat sandy beach merges into hills of blown sand.

The means of protection may also be divided into two general classes; one where the operations of Nature are taken advantage of by holding up the shingle and using it as a barrier to the waves and a protection to the cliffs; the other where the artificial works of man, in the form of sea walls, are made to offer a solid opposition to the attacks of the waves.

There is considerable difference in the qualifications of the two systems to withstand the encroachment of the sea.

In the first case the waves breaking on a shingle beach become gradually diffused amongst the shingle, expend their energy in rolling it about, and retreat without having done more harm than level the shingle down to a flat gradient on the beach.

With sea walls the whole force of the mass of water contained in the wave breaks on the wall, which thus has to withstand a very violent shock; the kinetic energy contained in the wave is expended in throwing the water upwards, which, falling back on the beach at the foot of the wall, erodes the material, so that the foundation, if not properly protected, becomes undermined, the wall being thus the agent of its own destruction.

The illustration (*Plate* I.) of the wave breaking on the promenade at Hastings during a storm in 1898, at a part where the shingle had been scoured away and the beach left bare to the chalk, on the lee side of a high groyne, clearly shows this eroding action. The depth of water in front of the wall is only that due to the rise of the tide which attains there to a depth of 15 feet at high water.

Force of Waves.

The enormous force expended by waves on sea walls and shingle beaches is difficult to realise.

Assuming the water of a wave to be projected upwards 10 feet and the whole mass of water to be falling from a mean height of 5 feet, the force of the blow on each square foot of beach where it falls is equal to 1½ foot tons, which, continuously repeated, is sufficient to break up and erode even hard material.

In Peterhead Harbour the water, due to a rise of tide on the foreshore of only 7 or 8 feet, has been known to strike the sea wall with such force as to be thrown upwards 100 feet.

It was calculated by the late Sir John Coode that during a heavy gale from the S.W. 3¾ million tons of shingle were torn down from the Chesil shingle bank and scattered on the beach; and on another occasion 4½ million tons were in like manner scoured from the bank by the waves; the shingle in both cases being gradually replaced by the tides after the gale was over. On one occasion, during a heavy gale and high tide, a laden sloop of 100 tons burden was carried on to the bank and lifted by the waves to the top, at a place where it was more than 30 feet above ordinary high water. During the recent high tides and gales boulders, weighing over 100 lbs., and great quantities of shingle have been thrown over the top of the bank into the village of Chesil lying below.

In the Solent, near Hurst Castle, during a gale in 1824, the shingle in a bank 2 miles long and 12 feet high was so disturbed that after the gale it was found that the whole bank had been moved back bodily 40 yards.

The same incident occurred at the Northam pebble ridge in Barnstaple Bay, where in a heavy north-west gale the bank for a length of 2 miles was driven back 30 feet, the clay base on which it rested being exposed to this extent on the seaward side; and stones weighing from 40 to 50 lbs. were thrown over the top on to the land behind.

On the east coast of Ireland during heavy gales 15,000 to 20,000 tons of sand, lying in the zone between high and low water, have been known to shift and be carried along the shore and deposited in a new position.

These examples are sufficient to show the forces that have to be contended with in works for shore protection.

As the force of the waves that beat against a sea wall or cliff and cause destruction is governed by the depth of the water on the foreshore in front of the wall, it is obvious that it is of paramount advantage to prevent the erosion of the beach and the drift of the shingle from the face of the cliff or wall, and also, where material is available, to arrest its progress and accumulate it on the beach to be protected.

Function of Waves and Tides on Beaches.

The sand and shingle on a beach are derived from the waste of the cliffs. The supply of this material is due to the action of the waves and tides.

The function of the wind waves is to break down the cliffs; to sort the material displaced; to grind up the larger rock fragments into sizes sufficiently small to be acted on by the tides; and to disperse material when, under tidal influence, it has been collected in large quantities.

The function of the tides consists in raising the water of the ocean sufficiently high to enable the waves to roll over the beach and attack the cliffs; in assisting in the grinding up of the rock fragments by their perpetual oscillating movement; and in acting as the chief agent in transporting the shingle along the coast and building it up into banks above the level of high water.

In considering the large deposits of sand by which beaches are covered, and of shingle banked up in various places along the coast, the fact must not however be lost sight of that the operating causes have been in existence for very long periods, and from remote times, under conditions different from those that now prevail; and that the quantity of beach material now being produced by coast erosion bears a very small proportion to that due to the mighty forces which were at work on the breaking up of the glacial period, when enormous volumes of water were sent down from the land, then covered thousands of feet deep by ice and snow, and gave to the country the physical surface conditions that now prevail.

Natural Protection.

Dealing first with natural protection by the preservation of the beach, attention may be called to the fact that coast erosion is most in existence where the shore is bordered by cliffs; and that by the erosion of these cliffs material is provided for the protection of the beach.

Sand Beaches.

On shores where there are no cliffs the country generally is of a flat character and there is an absence of shingle on the beach, which under such conditions is covered with sand lying at a very flat slope representing an equilibrium of the wave forces. Sand beaches retain their shape and position for long periods without material alteration.

The slope of such beaches varies from 1 in 10 to 1 in 200. On flat shores the water of the breaking wave is distributed over a wider horizontal range than on beaches where shingle exists, and it comes in contact with the beach at a much larger angle; the force of the impact is therefore smaller, and its effect on the beach less mordant. The waves breaking seaward of the low water line spread over the sand, diminishing from less and less to nothing till the margin of high water is reached. The whole energy contained in the breaking waves is thus dissipated in friction, and except in abnormally high tides they reach the shore in a comparatively harmless condition.

On the shore of most of these long sandy beaches are to be found extensive banks of sand known as dunes, which form the protection of the low land lying behind from the water of high tides. Such banks are to be found in this country on the Lincolnshire, Norfolk, Lancashire and other coasts.

On the opposite continent a continuous line of dunes extends for 1,000 miles from Calais to the Texel, and thence along the coast of Jutland and Schleswig-Holstein, in some parts rising to a height of 150 feet. These dunes form the only protection of the low lands of the Netherlands from the sea.

In Gascony, on the west coast of France, the dunes average 3½ miles in width and attain a height of 300 feet, extending over a length of 150 miles of coast.

These dunes are formed by the sand being blown off the beach during on-shore gales. If not arrested the sand, in course of time, travels shorewards burying the land with houses and churches in its course.

On the coast of Norfolk the sands advancing inland completely buried the village and church of Eccles; and in the Landes several villages with their churches, farms and vineyards, and even a small market town, now lie buried several feet under the dunes.

The encroachments of the sand may be checked by planting the banks with marram grass, or other similar plants having long roots that bind the sand together and prevent its drifting, and by planting fir trees. A successful example of the latter work may be seen on the Norfolk Coast, where by planting fir trees Lord Leicester has entirely prevented the encroachments of the sand on his estates, while at the same time the trees have become valuable as timber.

The devastation that was being caused by the advance of the sands in Gascony has also been arrested by the same means, 200,000 acres of sand dunes having been planted with fir trees, which, while arresting the devastating march of the sands, have rendered the district very healthy and yield a large revenue from the timber and tar obtained.

The condition of sandy beaches may be greatly improved by the use of low groynes running out at right angles to the shore as far as low water. By this means gullies and shallow creeks in the sand become filled up; and the creation of channels running parallel with the shore near the line of high water, caused by the plunge of the waves in gales, is prevented. If the beach is very flat, these low groynes also assist in causing the sand to shift shorewards and so raise the beach at the upper end.

Several beaches on the coast of this country and in Belgium have in this manner been greatly improved during the last few years by the construction of low groynes.

Shingle Banks.

Where the sea margin is bordered by cliffs the beach assumes a different character.

As a rule there is to be found at the foot of cliffs a bank of shingle more or less wide, the top of which is from 6 to 8 feet above high water. The seaward face of this shingle bank lies at a steep angle, generally 1 in 2½. After heavy on-shore gales, this seaward face of the bank is pulled down and levelled on the beach, and left at an angle of 1 in 10.

This shingle bank, except after storms, rarely extends seaward beyond the line of mean high water; below this the beach consists of sand.

In some cases these shingle banks have assumed large proportions, and the material has been shifted, by the action of waves and tides, far beyond the cliffs from which it has been derived.

The most notable of these banks in this country is that known as the Chesil bank in Dorsetshire (*Fig.* 1). This bank extends for

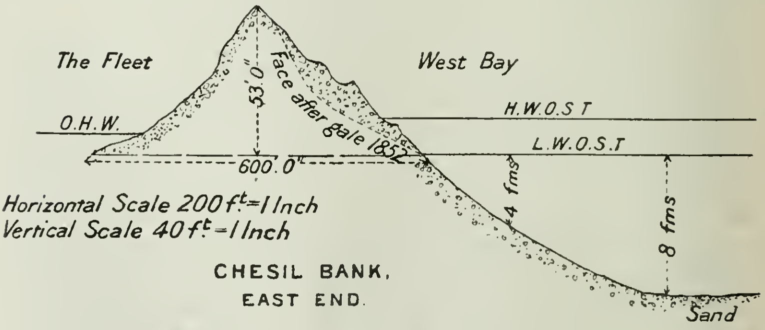


Fig. 1.

10¾ miles along the sea margin from Abbotsbury to Portland, the base being 500 feet wide and the top from 20 to 40 feet, the height varying from 32 to 53 feet above low water.

The shingle bank at Aldborough on the east coast is 9 miles in length, the top being 8 feet above high water of spring tides. This bank has drifted away from the cliffs, and reclaimed a large tract of low marshes, the river Alde having been diverted from its course the whole length of the bank.

The Hurst shingle bank extends for 1½ miles from the termination of the cliffs at the east end of Christchurch Bay along the Solent, the top being 12 feet above low water.

But perhaps the most remarkable bank is the one on the south-east side of Barnstaple Bay, extending for a distance of 13 miles along the base of the cliffs. Beyond this there is a pebble ridge, running north-east across the bay, which is 2 miles in length and forms a natural embankment enclosing 900 acres of what was formerly salt marshes. This pebble ridge is about 180 feet wide at the base and 25 feet at the top, which is 6 feet above high water; the material of which it is composed varies from small pebbles an inch in diameter to boulders 15 to 18 inches in length, weighing from 100 to 150 lbs.; the average size may be taken as from 8 to 12 inches in the longest diameter, and weight from 40 to 50 lbs. These boulders consist of hard carboniferous grit derived from the cliffs at Hartland Point, and have been rolled by the waves a distance of 8 or 10 miles. When the tide is up they are in continual motion. The description of this bank by Kingsley in his novel of *Westward Ho!* will probably be in the memory of most; he describes the sea as having defeated its own fury by rolling up in the course of ages for the protection of the land a rampart on which the waves, breaking at high water and continually rolling the boulders up and down its sea slope, cause a loud murmur which may be heard at a considerable distance inland; and when the mighty surges, due to a ground swell rolling in from the ocean, break on the bank, this murmur increases to a loud roar which he describes as "the everlasting thunder of the long Atlantic swell."

The shingle found on beaches, except in the special deposits already referred to, consists of pebbles derived from fragments of the harder rocks, flint from the chalk, or boulders and gravel from the deposits of glacial drift which form the principal cliffs on the east coast south of Flamborough Head and on the coasts of Lancashire and Cumberland. The south coast beaches for the most part consist of flints from the chalk. The fragments eroded from cliffs of sandstone, although yielding a considerable quantity of material, rapidly become disintegrated and reduced to sand, and in case of limestone become dissolved by the action of the water.

There is no other source but the cliffs from which beach material can be derived. Shingle is never, as is sometimes stated, washed up from the bed of the sea. Occasionally on steep beaches during heavy on-shore gales boulders, with seaweed attached, may be found cast up; but, as a rule, while there is a constant drift of the finer particles of material seaward, nothing in the shape of shingle is washed upwards from below low water.

The amount of shingle is therefore limited; and as it forms the natural protection of the land bordering on the sea, its removal should be strictly prohibited. Legislative power enables the Board of Trade to prevent this, and this power is frequently exercised.

The following example will demonstrate the damage done by removing beach material. A short time ago a very large quantity of shingle, required for the concrete walls of the new dockyard at Plymouth, was removed from the beach in Start Bay in front of the fishing village of Hall Sands, which stands on the margin of the shore. This removal led to the shingle on the beach becoming lowered 12 feet over a length of 1½ miles and a width of 50 feet, causing the depth of the water at high tides to be increased. The waves, consequently having greater force, broke during on-shore gales with great violence on the quay wall that protected the village, gradually undermined it, and carried away the road and wrecked several houses, to the very serious loss of the fishermen and inhabitants. During the recent gale and high tide more of the shore has gone and six more of the houses have been placed in danger.

Direction of Drift of Shingle.

In addition to the up and down movement of pebbles on banks through the action of the waves and tides, there is a regular and continuous movement in one given direction. A temporary check may be put to this forward movement by gales blowing onshore and pulling the shingle down and levelling it; or by gales blowing in a contrary way to the normal forward movement. This action of wind waves however is only occasional and intermittent, while the normal travel is constant, except under the adverse conditions mentioned.

This regular and continuous movement of the shingle is invariably in the same direction as the set of the flood tide. Thus on the east coast the normal direction of the drift is from north to south; on the south coast from west to east; on the west coast, from the English Channel to Morecambe Bay, from south to north ; and north of this from north to south. In each case this is the direction of the set of the flood tide. This general direction may vary where the tide sets into bays or round headlands (*Fig.* 2), or where the normal set of the flood tide is altered by changes in the direction of the coast line or by breaks caused by estuaries. An example of this last is to be found on the east end of the English Channel (*Fig.* 3) ; the direction of the drift from Bognor to Beachy Head is easterly, from Beachy Head to Dover north-east, from Dover to the North Foreland northerly, from the North Foreland to the mouth of the Thames westerly, and north of the Thames south-westerly ; in each case the set of the drift and of the flood tide along the shore are the same.

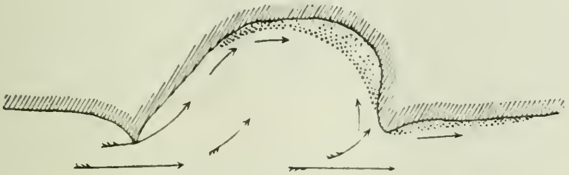


Fig. 2.

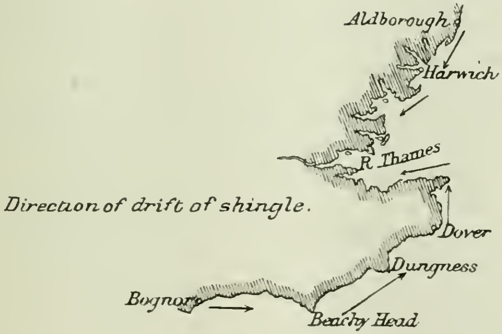


Fig. 3.

Effect of Tidal Action on Drift.

It is generally stated that the movement of shingle along the coast, and the building up of the banks, is due to the action of the prevailing winds. It has already been shown that, while the movement of the shingle is regular and continuous in one direction, the wind is intermittent and its direction various ; further that the movement of the shingle goes on in calm weather; that within a limited range of coast, where the direction of the prevailing wind can only be from one quarter, the regular and continuous direction of the drift varies considerably, invariably coinciding within this limited area with the direction of the flood tide; and that shingle banks, which are pulled down and destroyed by on-shore gales, are built up again during calm weather or when the wind is off shore, so that the gales cannot have much effect in the movement of the shingle. It is obvious therefore that the tides must have some direct connection with, and influence on, this movement.

The action of the tide in moving material may be explained as follows:—Observations of the flowing or ebbing tide on even the flattest beach, when there has been a calm for several days and the sea is quite smooth and when a boat lying in the offing has no perceptible motion, will show that the rise and fall of the tide is not effected by a mere vertical swelling and depression or rise and fall of the water; but that it is accompanied by a series of small waves, varying in height, according to the flatness and steepness of the beach, from 6 to 24 inches and occurring at a frequency of 10 or 20 a minute. These wavelets are never absent from the shore, except when absorbed by larger waves due to gales.

The occurrence of these wavelets may be thus explained. As the tidal wave of the open ocean approaches the coast and encounters the shallow water of the beach it changes its character. Owing to the friction on the bottom, the water near the shore lags behind that in the open ocean, and therefore moves along with an oblique motion. The flowing water being also checked by the shoaling is reflected back, and a series of small oscillations or waves is set up, which break as they reach the shore.

These wavelets, striking the shore obliquely as the tide rises, lift up the pebbles lying on it and carry them forward to the existing pebble ridge; and at the same time, on coming in direct contact with the bank, they push upward and forward those with which they come in contact. The movement of the pebbles on the face of the bank is actuated by the momentum of the wedge-shaped mass of water into which the wave has been resolved.

This process, continually in operation by each successive wave for several hours twice in the day, is sufficient to account for the removal of an immense amount of material.

Assuming that the kinetic energy contained in each wavelet 10 feet long and one foot high is capable of lifting 156 lbs. of pebbles one foot high, each wave, for every foot in width, is capable of moving 660 pebbles two inches in diameter which amount to 2,376,000 in one tide.

ARTIFICIAL PROTECTION.

For the protection of any given part of the coast this regular and continuous movement of the shingle is arrested by placing an opposing obstacle to its travel in the form of groynes constructed of wood or concrete. Groynes.

The shingle, being unable to pass the groyne, accumulates on the windward side and forms a bank at the foot of the cliff or sea wall, the top of which, rising above the level of high water, stops the erosion of the shore or the beach at the foot of the wall.

It is essential to ascertain the direction from which the regular and continuous drift of material takes place, as groynes require to be supported on their lee sides in order to withstand the pressure of the accumulated shingle.

It is useless putting down groynes unless there is material drifting along the shore which can be collected. They do not create shingle, and are useless for moderating the force of the waves, as is sometimes supposed. This may be realised by the illustration (*Plate* I.) of the waves breaking on the promenade at Hastings during an on-shore gale, this sea front being as much groyned as any part of the coast in the kingdom.

Groynes may be the cause of damage to the shore lying on their lee side. Numerous instances may be found along the coast where an owner, to protect his front, has run out groynes and so arrested the travel of the shingle to the coast beyond, which in due course has become denuded of the shingle previously existing; all further supply being thus arrested, the beach has been laid bare and erosion has commenced where previously immunity from this was enjoyed.

A striking example of this is to be found at the present time at Lowestoft (*Plate* II.). The owner of the land at Corton, to the north of this place, constructed a series of groynes which prevented any fresh supply of beach material drifting southward; and the beach becoming partially denuded of shingle, the high tides began encroaching on the land. On the south side of the harbour the matter became much more serious. To save the shoaling of the harbour from the south drifting shingle the owners had built a long wooden groyne to the north of, and seaward of, the harbour mouth, and thus arrested the travelling shingle which has since been accumulating at the back of this groyne. Meantime, the supply being thus cut off from the south beach, the latter became gradually denuded and its surface lowered. This action was further aided by the construction of a sea wall along the foot of the cliff at Pakefield; the waves breaking on this wall cut out the beach at its foot and, their energy being increased by the greater depth of the water, they fell with great force on the concrete decking of the promenade, tearing it up and washing out the material from behind so that the whole promenade became a wreck (*Fig.* 1, *Plate* III.). Where the cliffs were not protected they were washed away, letting down the roadway and houses above them; the sum required to restore this wall will amount to several thousand pounds. Now that this and other serious damage has been done and when the greater part of the shingle has been washed away, groynes are being constructed which have prevented further denudation and have already led to some accretion on the upper part of the beach.

The same result has taken place at Sheringham, where the landowner on the windward or west side built a groyne which arrested the travel of the shingle towards the town, where a sea wall and promenade have recently been built. A large groyne, which had formerly been built on the east or lee side to hold up the shingle, was at the same time allowed to go to ruin. In consequence, the supply of fresh material from the windward beach being arrested, and that which formerly existed in front of the town being allowed to drift away to the east, the beach at the foot of the sea wall has been eroded and lowered several feet. The beach being also cut out by the action of the return waves from the wall, the whole promenade has become placed in considerable danger; and the shore, which was formerly used by the fishermen as a safe place on which to lay their boats, can no longer be used for that purpose.

At Hastings, since the construction of a long concrete groyne at the east end of the frontage and of the piers for the new harbour, all travel of shingle eastward has been prevented; and while there is a large accumulation on the west side of the harbour, the beach on the east side has become bared down to the chalk.

The same is the case at Brighton; the groynes placed in front of Hove and the west end of Brighton have stopped the travel of the shingle eastward; the beach in front of Kemp Town and towards Rottingdean is now bare of shingle, and the sea is causing constant erosion of the shore and cliffs.

Groynes have been constructed in many ways and of different lengths and sizes.

On the south coast the beach may be seen cut up into small bays by high and massive timber or concrete structures, some of which have cost £10,000 each ; the shingle is heaped up from 10 to 20 feet on one side, with none on the other; the beach is thus rendered excessively inconvenient for visitors, and the accumulated shingle is so disadvantageously distributed that, while reaching nearly the top of the wall for part of its length, another part is left quite bare down to the chalk, the wall being thus exposed over part of its length to the full force of the waves.

At Hove heavy timber groynes (*Fig.* 4) have been adopted ; these rise 16 feet above the beach, and are held in place by unsquared oak trees from 30 to 35 feet long ; these supports, unlike those of all other groynes, are placed on the windward side and therefore act in tension. Groynes of this character cost about £6 per yard run.

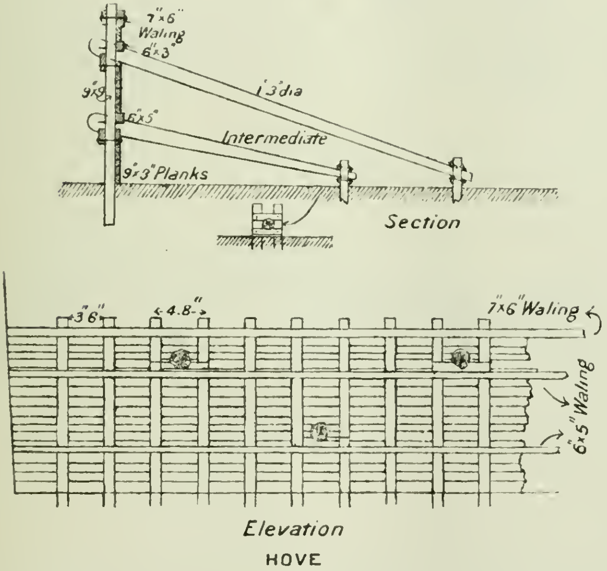
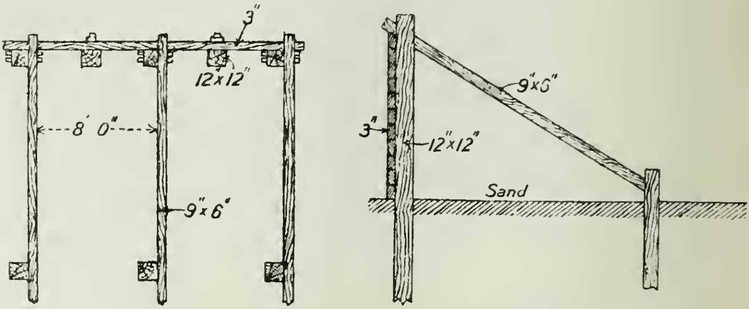


Fig. 4.

The groynes constructed under the directions of the Board of Trade for the protection of the Spurn peninsula at the mouth of the Humber (*Fig.* 5) may be taken as successful examples of protective work. These consist of 3″ Baltic fir planks, fastened by ¾″ bolts to 12″ × 12″ fir piles driven 10 feet into the clay beach, the piles being supported on the lee side by 9″ × 6″ struts. They are 100 yards in length and 200 yards apart. They have been very successful in arresting the travel of the shingle, which has accumulated to a considerable extent, the quantity thus gathered being estimated a few years ago as 1½ millions of tons. This bank of shingle has formed a complete protection to the shore, which had become in a dangerous condition owing principally to the constant removal of shingle for road repairs and making concrete ; it was estimated that the quantity of shingle removed by barges for this purpose amounted to 60,000 tons a year, but this was stopped some years since by the Board of Trade.



Plan

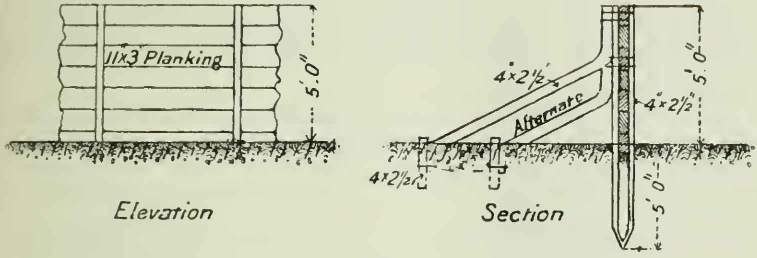
Section

SPURN POINT

Fig. 5.

The cost of such groynes as these may be put approximately at £5 per yard run or £500 each ; if spaced 200 yards apart, the cost of protecting a mile of coast would be £4,400.

Groynes of similar character have been used at Sandgate (*Fig.* 6) and Seabrooke, old railway metals being used for posts and struts.

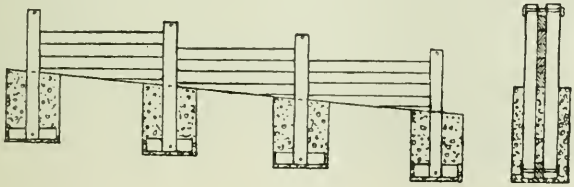


Sandgate

Fig. 6.

Lighter groynes, suitable for sandy beaches such as are to be found at Worthing, Felixstowe or Sutton-on-Sea, consist of planks spiked to light piles; or, as at Bridlington, a row of short square piles driven close together, their top being about 2 feet above the beach.

What are termed Case groynes (*Fig.* 7) have been adopted on several parts of the coast, with varying and doubtful success. They consist of two upright planks bedded in a concrete base, with other planks fixed horizontally between them in steps instead of raking with the slope of the beach as with other groynes.



CASE GROYNE

Fig. 7.

The cost of these low groynes may be taken as £1 a lineal yard, or £100 each groyne, making the cost of protecting a mile of coast £1,407.

The length of groynes and their distance apart varies greatly; but the general rule is to extend them from the shore or cliff to low water S.T. or, where the shingle is abundant, to low water N.T.; where a beach has been much denuded it may be desirable to extend beyond L.W.S.T. Good results cannot be obtained with short groynes.

With regard to the distance apart, this is generally taken as equal to, or 1½ times, the length of the groyne. Groynes placed near together, especially high structures such as those described at Brighton, Hastings, Eastbourne, etc., are not in practice found to give satisfactory results, while they make a very uneven beach and entirely spoil it for visitors. Low groynes placed near together are also much objected to by fishermen and boatmen, as being a source of great danger when bringing their boats on to the beach.

As the only use of groynes is to prevent the drift of the shingle away from the frontage to be protected, there is no advantage in placing them nearer together than is sufficient to accomplish this. A length of 600 yards of coast may be effectually protected by a single groyne placed at the leeward end of the part to be protected (*Fig.* 8). The effect on the beach with a single groyne may be seen by the illustration, in which the light lines across the beach indicate the distance apart and the number of groynes that are generally used. The cost of protecting a mile of coast in this way may be put at £1,670.

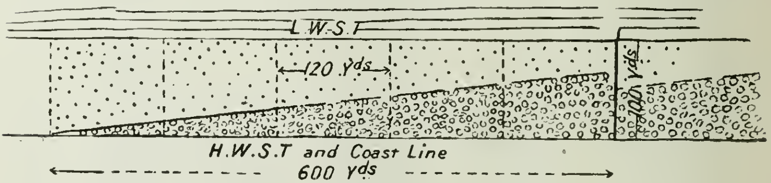


Fig. 8.

With regard to the line of direction, the best results for a given length of groyne are obtained when it is placed at right angles to the shore; the worst results when it makes an angle with the shore towards the windward side or that from which the shingle comes. Groynes sloping to leeward, or away from the source of supply, are used by some engineers with the idea that they lead to a more even distribution of the shingle on both sides of the groyne; but an examination of beaches where the groynes are pitched at an angle of 100 to 120 degrees with the shore does not bear this theory out.

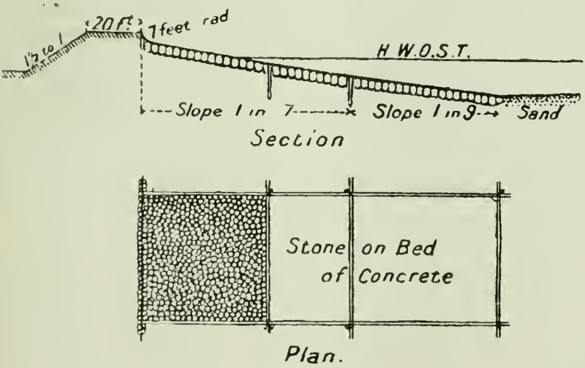
As regards height, there is no advantage in carrying a groyne above H.W.S.T.; and it is desirable to make the planking only two or three feet above the beach at first, and raise it gradually as the shingle accumulates. Groynes, the top of which rise much above the beach, only lead to an increase of wave action and erosion of material.

Sea Walls.

When no natural protection to the shore can be obtained by means of beach material sea walls have to be resorted to. These are of two kinds, sloping and upright, the former being most commonly used for the protection of the land and the latter for the maintenance of roads and promenades.

In Holland sloping walls, made of earth and protected on the face with stone pitching, have been very largely used; one of the most extensive is that at Petten, which protects 70,000 acres of low land in the Island of Walcheren. This bank is very exposed, there being a fetch of 2,000 miles in face of it. It is 2½ miles long; its top is 16 feet above average high tides, and its width 40 feet at the top; the sea slope averages 1 in 14. The face is pitched with basalt at the lower part, and with clay and straw matting above high water. The foot is protected by a wooden stockade, composed of 11 ranges of piles 6 inches in diameter and projecting about 3 feet.

For sea defence works in this country earthen banks are very little in use. Those at Dymchurch (*Fig.* 9) for the protection of 60,000 acres in Romney Marsh, and that at Blackpool (*Fig.* 10) for the protection of the road and promenade, are the most conspicuous examples.



DYMCHURCH.

Fig. 9.

The Dymchurch bank is 4 miles long; the top is 20 feet wide, and

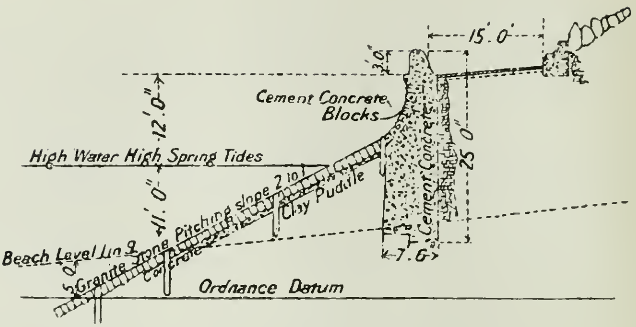


Fig. 10.

10 feet above high water; the face of the bank slopes at 1 in 8 and is protected by stone pitching placed in timber bays, piles and waling being driven into the face at intervals of 50 feet. The area of the pitched slope covers 40 acres; the cost of repairs to the pitching amounts to about £3,000 a year. In heavy gales as much as 18,000 yards of the stone pitching have been torn out.

The Blackpool bank is a modern construction, made of earth with a pitching of rough granite blocks laid at an angle of 1 in 2; it is divided into panels, about 20ft. square, by planking fastened to piles. The top of the wall is 12 feet above high water.

With upright sea walls the strain that has to be contended with differs from that of ordinary retaining walls; in addition to the static pressure of the earth at the back, the face is exposed to the hydrostatic force of the water, to the dynamic action of the waves breaking on the face of the wall, and also to the destructive and eroding effect of the water falling on the beach at the foot.

The waves which a sea wall has to encounter also vary from those with which piers and breakwaters have to contend.

The normal action of a wave, in water sufficiently deep to allow of its completing its motion within its orbit, is one of undulation, the motion being vertical; but where the water is shallow, the motion of the lower part of the wave is obstructed while the upper part progresses more rapidly, so the wave curls over and the whole mass of the water is thrown horizontally forward on to any obstacle that interferes with its progress. This may be best realised by comparing the action of the water on a sloping breakwater with that on an adjoining upright wall where the water is deep; in the one case the waves will be seen dashing against the slope with great violence, whereas at the same time against the upright wall there may be only a gentle undulation.

The effect of waves breaking on sea walls is shown in the illustration of the storm at Hastings (*Plate* I.), where the water in gales has been thrown through the windows into the bedrooms of the houses on the other side of the road and has covered the promenade with shingle.

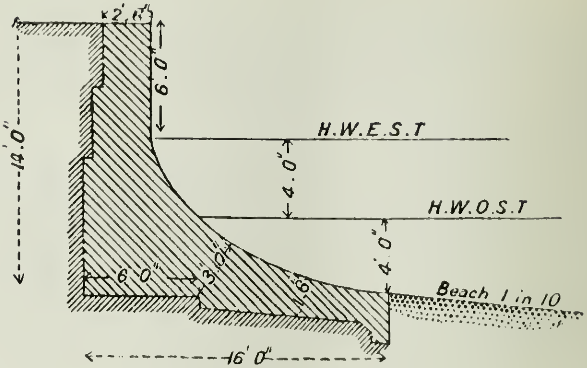
The main point to be observed in the construction of walls for coast protection is that the shape be such that the greatest force of the wave shall strike the wall at a point where it can do least harm. The greatest blow occurs where the horizontal motion of the broken wave changes into a vertical one; the wave, when it strikes the wall, should be deflected and not broken; so all projections and obstructions to the free movement of the wave, such as bull noses and cornices, should be avoided, as the vertical wave striking these has a tendency to lift and disrupt the masonry.

A wall with too much batter leads the water over on to the back; and in one that is too vertical, and has no toe, the falling water cuts the beach away and undermines the foundation. A wall having an elliptic or curved face with the curve continued upwards is frequently adopted with the idea that the water driven round the upper curve falls back on the coming wave and so counteracts and diminishes its force; but experience shows that the mass of water, being increased by the union of the receding and coming wave, breaks with greater force on the wall. Such walls are also weak in construction, as the upper part is exposed to the force of the upward vertical column of water which it has little weight to resist.

The most effective form of wall is one that has a cycloidal or elliptical form at the foot, dying out into a vertical face at the top, the foot having a toe sloping to the beach at the same inclination as the natural angle of repose of the material of the beach.

Such a form is shown in *Fig.* 11. With this the strongest part of the wall is where the heaviest wave impact takes place. The wave is led gently from the horizontal to the vertical motion where the curve occurs; the water is not led over on to the back of the wall; and the receding wave falls on to the sloping toe, where it again changes into the horizontal motion with the least disturbance to the beach.

It is rarely that a sea wall fails from general weakness of construction or is pushed over by the lateral thrust of the earth at its back. The most frequent cause of failure arises from the fall on to the beach of the water of the return wave, by which the material of which the beach is composed is cut out, loosened and washed away; or else, if the water falls on to the back of the wall, the earth is washed out leaving the wall bare. An illustration of this last is



Scale 1 inch = 10 feet
Fig. 11.

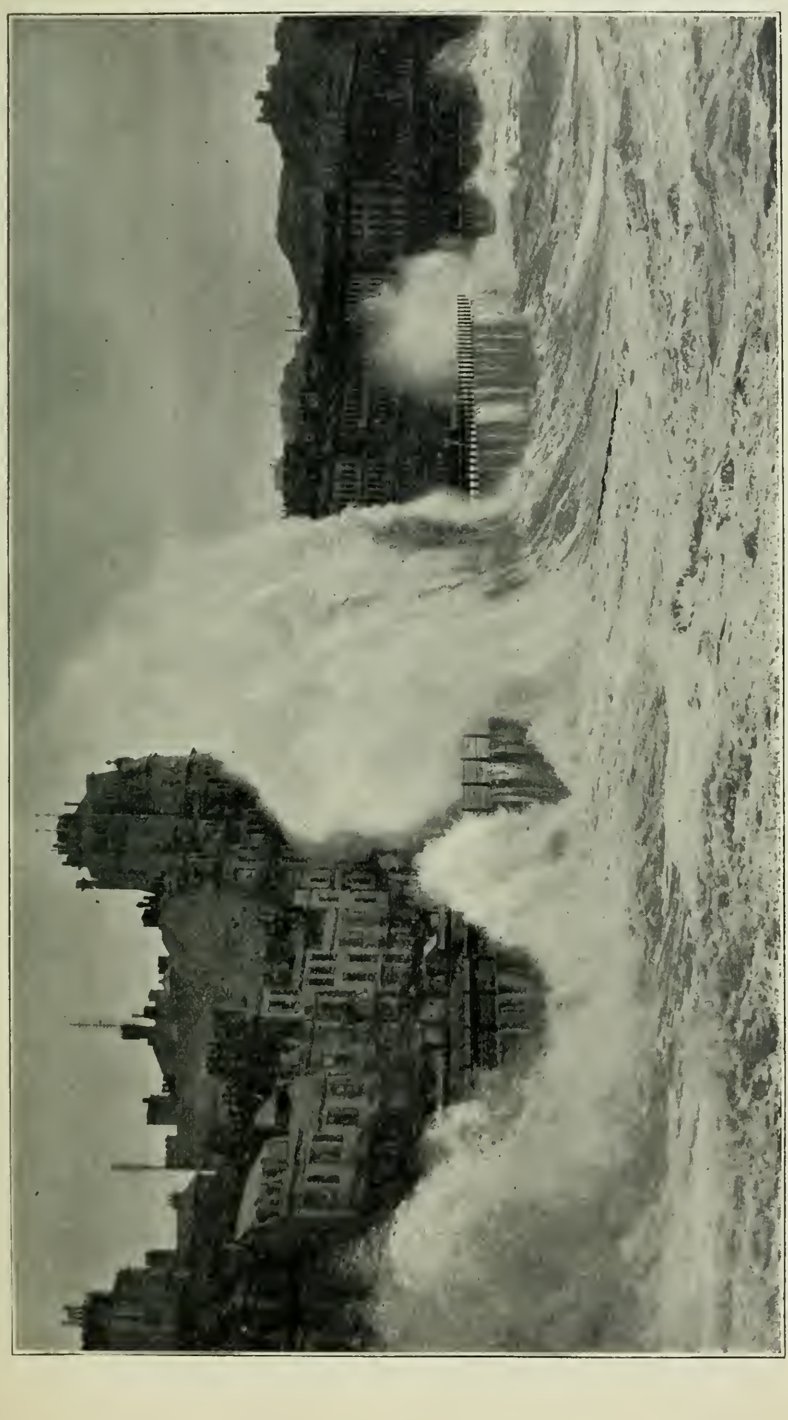
given in the fate of the sea wall at Dover during a recent storm, the sea breaking up the concrete decking of the promenade and washing the earth away from the back of the wall (*Fig.* 2, *Plate* III.). The same thing occurred to the Lowestoft wall already referred to.

Another instance of this eroding action is that of the sea wall at Hove, the base of which was carried 9ft. below the lowest level to which the beach had ever been known to scour, and when completed there was 9ft. of shingle on the beach in front of it. After the wall was completed, the effect of the waves breaking on the beach at its foot caused the whole of this shingle to be eroded and carried away, and the beach was left exposed down to the chalk. To prevent the wall collapsing it became necessary to protect it by sheet piles. By the erection of groynes and the discharge on the foreshore of a large quantity of shingle, dredged from Shoreham harbour, a beach was again formed and has since been maintained.

At Margate, Ramsgate and Westgate, where the walls were let into the solid chalk underlying the beach but were not protected by beach material, the downward action of the waves, after breaking on the walls, eroded the chalk; in one instance the wall was undermined to a depth of 4½ feet and had to be underpinned, and in another the wall entirely collapsed.

It has only been possible, in the time allotted for this lecture, to touch briefly the general subject of coast erosion and protection; but there are many other points of great interest which require careful consideration before any works are undertaken for preventing the destruction action of the sea on Sea Coast.

PLATE I.



SHORE WAVE BREAKING ON SEA WALL, HASTINGS.

PLATE II.

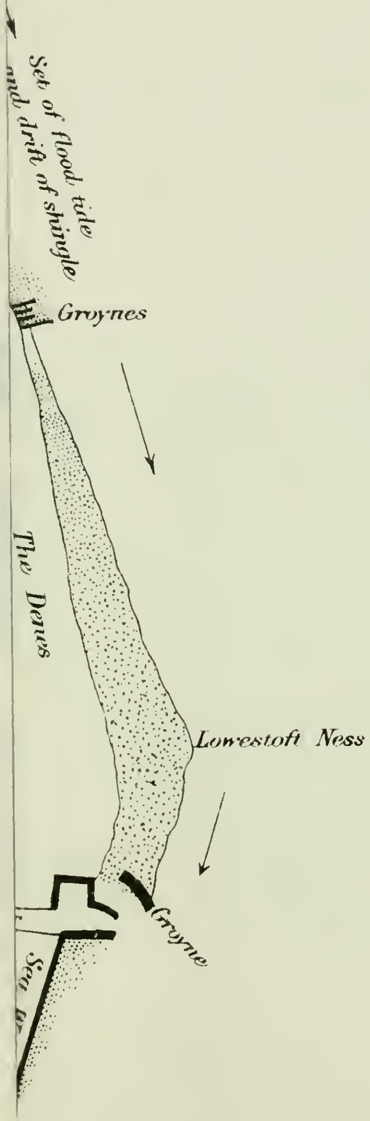

Set of flood tide and drift of shingle
Groynes
The Denes
Lowestoft Ness
Groyne
Sea W

PLATE II.

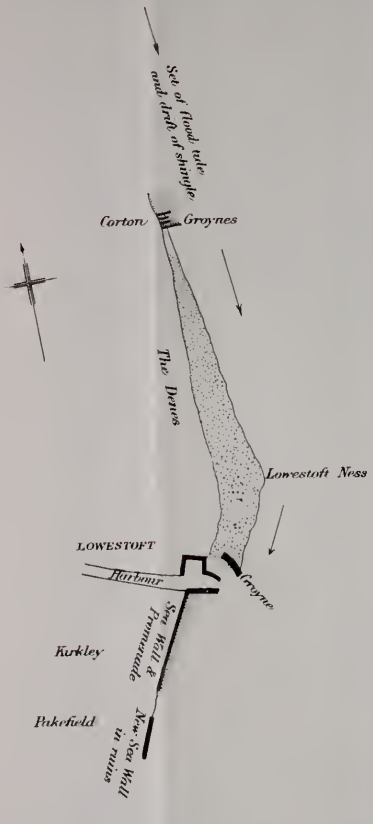
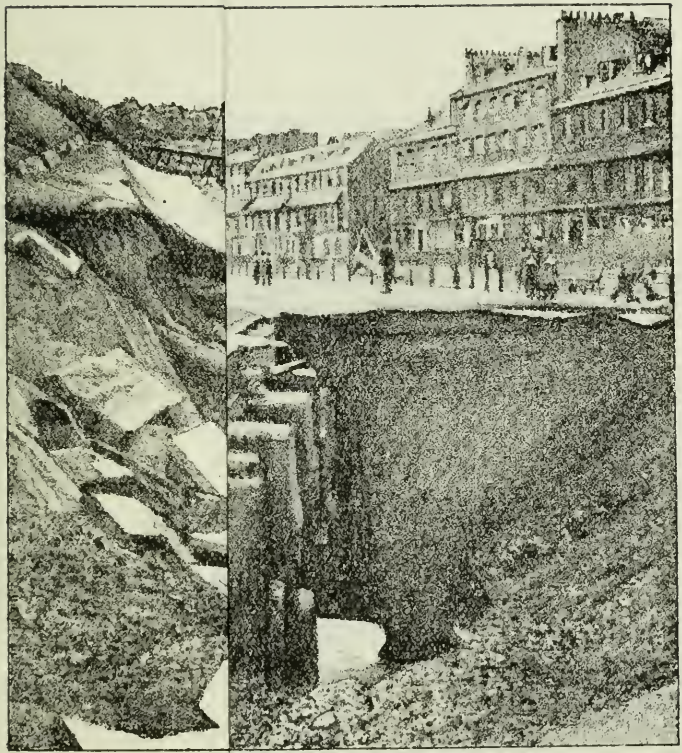

Set of flood tide and drift of shingle
Corton
Groynes
The Denes
Lowestoft Ness
LOWESTOFT
Harbour
Groyne
Sea Wall & Promenade
Kirkley
Pakefield
New Sea Wall in ruins

PLATE III.

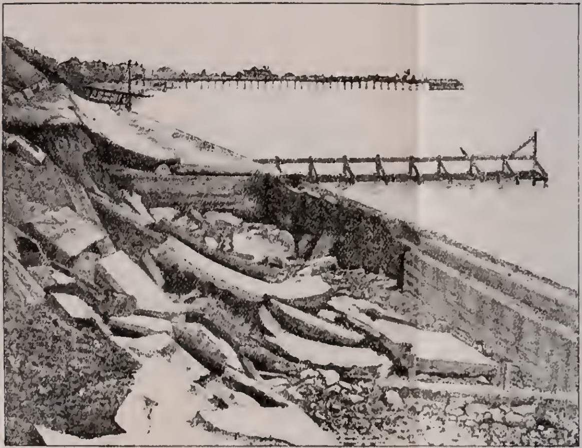
Fig. 2.



THE HOLES MADE IN THE
DA PARADE AT DOVER.

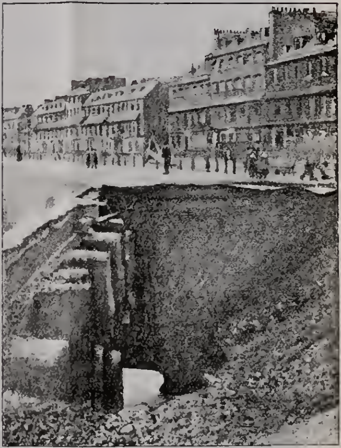
PLATE III.

Fig. 1.



DAMAGED SEA WALL AT LOWESTOFT.

Fig. 2.



ONE OF THE HOLES MADE IN THE PARADE AT DOVER.

PAPER VI.

SEWER VENTILATION.

BY

WM. BROWN, ESQ.

(Lecture delivered at the School of Military Engineering, Chatham, on 16th March, 1904).

SEWER VENTILATION.

A SUBJECT which is at once so large and so seriously complicated as Sewer Ventilation cannot be dealt with exhaustively in one lecture of reasonable length ; I therefore propose to deal with it as follows:—

(1). The importance of Sewer Ventilation.
(2). The fallacies which have hitherto beset its practice and impeded its beneficent operation.
(3). The remedy.

It is not my intention to divide the lecture into three separate compartments so to speak ; but I have mentioned these points now, in order that from the outset we may have a mutual understanding as to the scope of my present object as a whole.

In speaking of the importance of sewer ventilation I wish to attach a very special significance to the word "importance." My own sense of the importance of sewer ventilation to the well-being of civilised life has grown upon me with the study of the subject during the past dozen years ; during these years I have been, as it were, an eye-witness of the great injury to health and life which, year by year, has taken place owing to misdirection in connection with our sewer ventilation practice. I refer to the incidence of preventable disease ; this of course can easily be obtained from statistics, but no figures can ever show us the equally important lowering of the general vitality which is due to the same cause.

In view of this I will not be misunderstood when I say that I feel the present a great opportunity, and let me add without any affectation that the weight of the responsibility of wisely using it does not press lightly upon me. I cannot forget that those present will at some future time be called upon to decide practical measures, the issues of which may be either health and life or disease and death, perhaps even on an unthinkable scale, according as their minds may be influenced by this lecture.

In what special sense then do I use the word importance? You are all willing doubtless to grant that the subject is important. But I wish if possible so to appeal to your judgment that you will see its importance in a similar degree to that in which it appears to myself.

Let me recall a well-known incident; as an illustration it serves a double purpose. In this case the prevailing conception of the importance of sewer ventilation was considerable, because it was strong enough to inspire a great effort to get at the truth about it. How inadequate the conception must after all have been may be measured by the sadly disproportionate results which followed the effort.

Nearly ten years ago the Town Commissioners of a popular health resort instructed their Clerk to report for their guidance upon the question of Sewer Ventilation. The report was published in March, 1895. It bears on the face of it that authorities of all kinds had been referred to and scientific volumes ransacked, and that the current literature of the day had been watched for the latest scientific or practical word on the subject. I have a personal reason for remembering the latter circumstance for, after the report had been closed, it had evidently been re-opened to insert a reference to a series of articles then recently contributed by me to *The Surveyor.*

In addition to diligence in the directions just alluded to, the Clerk sent out schedules designed to elicit the practice which obtained in other towns. Of these no fewer than 202 were returned filled up; and these were all tabulated systematically.

The grand sum total of the information thus collected having been arranged, this was the conclusion of the whole matter as set forth by the Clerk in his report:—

> "Sanitary Engineers, Surveyors and experts throughout the United Kingdom have devoted much anxious thought to the consideration of the question in all its various ramifications from a professional standpoint. Numerous valuable reports and suggestions have been presented, and a variety of painstaking experiments in all directions has from time to time been made by the more prominent advocates of different

> systems. But I think, after an unprejudiced and impartial perusal of the various details contained in the appendix, the Members of the Board will experience no difficulty in agreeing with the conclusion to which I, as a layman, have arrived, that a thoroughly satisfactory solution of the great and apparently interminable difficulties which are involved in, or appurtenant to, the question has not up to the present time been arrived at; nor indeed is such a desirable consummation likely to be reached for a very considerable time, so various, so perplexing, so intricate, so diametrically opposed in many instances are the views expressed, and the opinions held, by those who by training, by profession and by practical experience are better qualified, and undoubtedly more competent, to judge of the merits of the different methods adopted and recommended. This view it will be observed is confirmed and corroborated by professional opinions in the replies received from the following places :—"

I know of nothing in all literature which is more farcical, but at the same time more tragic in the issues involved, than this report, especially when it is remembered that the effort to get at the truth was so earnest and the conclusions as set forth so conscientiously arrived at.

It may be said that was the record nine years ago and much has happened since. That is true ; much has happened since, which the ratepayers could have well dispensed with. But so far as sound practice is concerned, or so far as there is any general agreement as to what sound practice is, Sewer Ventilation is in very much the same position in this month of March, 1904, as it was in March, 1895.

There is, however, this very essential difference to be noted ;—whereas I have no principle to lay before you to-night that was not known in 1895 to all who read the articles in *The Surveyor*—that indeed was not known substantially in 1887 by all who read the paper of my friend Mr. R. Harris Reeves to the Sanitary Conference held at Worcester that year—, yet the evidence of the truth of the principles then laid down has so grown in weight as well as volume that its force can no longer be resisted.

Now with the assistance of some diagrams I shall endeavour to illustrate some of the points of the case which I have the pleasure of submitting for your consideration.

The Old Sewer Men.

A picture of an *old* sewer-man was used to illustrate an article in a London daily paper, the argument of which was that sewer-gas was not so bad for health as some supposed. The emphasis of course is to be laid on the word "old"; the man's age was given as 70 years, and he had worked as a sewer man for 47 years. But whether the air of the sewers of London tends to longevity or not will no doubt be sufficiently apparent before the close of the lecture.

Previous to the article appearing, the Lambeth and other fatalities had shown what danger really lurked in the London sewers; and about two months after its publication the memorable East Ham fatality occurred, in regard to which Sir Robert Rawlinson used the uncompromising and emphatic phrase "imbecility and ignorance all round" and insisted that what was wanted was "full, free and unceasing sewer ventilation." That was probably the last public utterance of this great 19th century sanitarian on sanitary questions. Surely these five East Ham heroes did not die in vain when their bravery and tragic fate together compelled the veteran engineer to write the valuable comments from which I have quoted, and which give the full weight of his great authority in favour of my present plea for the importance of sewer ventilation being better understood.

In the beginning of 1899 the County Borough of Salford issued "Directions to Workmen for dealing with Foul-Air in Sewers," and as they caused these directions to be published in the press for the benefit of others they evidently did not think their experience exceptional.

May I be allowed to quote from the comments I publicly made on these directions in March, 1899?

> "Direction No. 6, especially, ought to be reprinted in large letters, and posted in every Council room in the kingdom, until the present state of matters gives place to a better. It reads thus:—'When a man has to descend a risky manhole or shaft, he must have a strong rope properly tied about his shoulders, so that he can be lifted by it; and the rope must be kept in hand ready to lift him up if he becomes overpowered by the gas. When a man has to crawl along a risky sewer he must have a short rope securely tied to his ankles and a rope from it to the hand, so as to draw him back if he becomes overpowered by the gas.'

Is it justifiable that a man should have to crawl along a risky sewer as provided for in these directions? It is not,—for the simple reason that it is unnecessary.

I feel bound to insist on this, that no sewers should ever be in a state in which it is necessary for a man to crawl along with a short rope securely tied to his ankles, and a rope from it to hand, so as to draw him back if he becomes overpowered by the gas, that is, probably, with his mouth under the sewage during the process of drawing back."

SYPHONING OF TRAPPED GULLIES AT WESTMINSTER.

The air of the Houses of Parliament is notorious for its bad effects upon Members, and large sums have been spent with a view to finding a remedy.

There are no less than 14 gulley gratings along the edge of the footpath, close to the main wall of the Houses and the entrances, including the Victoria Tower; also 15 more in the vicinity.

You may ask, what have the gully gratings to do with the air in the Houses? Are the gullies not all trapped? Kindly note the number and position of these trapped gullies with reference to the various entrances, and also that the ventilating shafts are all securely shut down.

We have (*Plate* I., *Fig.* 1) the Houses of Parliament on one side the street and the Abbey on the other, with two sewers running between. The larger of these sewers is that of the London County Council. Something like a million gallons of sewage flow through it hourly. The gases contained in it, at times, must be very foul, but all openings are securely blocked or sealed and no harm can come to anyone—so long as they remain so.

But the effect shown in *Fig.* 2 sometimes happens. The sewers fill up and become surcharged, and the force of the compressed sewer gas then becomes so great as even to blow out of its seating a heavy manhole cover. It is not therefore difficult to understand how sewer gas can be forced through gully gratings no matter how deep the seal.

Then (*Fig.* 3) the sewage levels fall again, all the gullies are exposed to a powerful suction force, and the least resistant give way. Thus there are untrapped connections established between the very entrance doors to the Houses and an absolutely unventilated sewer, in fact two parallel unventilated sewers.

Syphoning of House-Drain Traps.

But the dangers to which our legislators are exposed, owing to the liability of traps to become unsealed, are but representative of the dangers to which every citizen is exposed who lives in a house served by a water carriage system of waste removal.

Plate II. represents a house-drain which discharges into a 12″ pipe sewer. When the sewer ceases to be ventilated owing to atmospheric changes, in summer months especially, gases of the worst character accumulate in the house-drain between the intercepting trap and the sewer. The more perfectly the trap acts the more dangerous do the gases become.

Sooner or later the pipe sewer fills as shown at "A," and the gases are forced through the trap as shown at "C." In due course the sewage level falls as shown at "H"; the solid body of water in the house-drain then acts like the plunger of a pump, the seal of the trap is broken, and a way is opened for the free passage into the dwelling house of disease-spreading air of the deadliest character.

The same result may follow when the Health Officer with the best intention orders an extra flush during warm dry weather. Thus there are drain-traps that sometimes prove veritable death-traps.

It is no part of my present plan to discuss the question of drain-traps, but I feel that I must say this much :—That the existence of traps complicates the sewer ventilation problem, that they would obviously be unnecessary if there was no sewer-gas (in other words, under a condition of perfect sewer ventilation), and that as a protection from imperfectly ventilated sewers they are far from being reliable.

Zymotic Cases at Fulham in 1893.

A plan of the Parish of Fulham showed :—(1) the Local Authority's pipe sewers, which in 1893 had a total length of 23 miles; (2) the Local Authority's brick sewers, with a total length of 8 miles; and (3) the main sewer of the London County Council, which was 4 miles in length.

After much careful measuring and testing Mr. Reeves analysed the deficiency of ventilation on this system of sewerage as follows :—

The 12″ pipe sewers	had	7½	times	too	little	ventilation.
The branch brick sewers	,,	45	,,	,,	,,	,,
The main sewers of the Local Authority	,,	63½	,,	,,	,,	,,
The main sewers of the London County Council	,,	185	,,	,,	,,	,,

Taking his information from the report of the medical officer of health for Fulham for 1893, Mr. Reeves plotted out on the chart the zymotic cases.

There were 30 cases of small-pox, 4 fatal; 230 diphtheria cases, 55 fatal; 701 cases of scarlet fever, 43 fatal. Total cases 961.

All the small-pox cases came from the vicinity of the worst ventilated sewer. Measuring however to nearest points, it was found that the average number of cases of small-pox per mile of sewer was 3 for the worst ventilated, $1\frac{1}{4}$ for the next worst and $\frac{1}{3}$ of a case in the least worst; one cannot very well use the term "best" in such a connection. The total cases located on the same plan as above gave the following figures:—$54\frac{1}{4}$, $28\frac{5}{9}$, $22\frac{6}{23}$ respectively.

LONDON SMALL-POX EPIDEMIC IN 1894.

In 1895, having been asked to review the report of the Metropolitan Asylums Board for 1894,—which was accompanied by a series of spot maps showing where each case of disease dealt with had come from—, it appeared to Mr. Reeves and myself that it might serve a good public purpose if we took the small-pox map, marked off certain distances from the London County Council main sewer, and compared the number of cases of small-pox coming from the areas so marked off with the number coming from the remainder of the area in the County of London. While this was still in progress my instructions were countermanded.

Unfortunately the original map has been lost but the figures, so far as they had been made up, were kept.

564 cases in 12 parishes were examined, 355 of which were located within 400 yards of the main sewer. Of the 260 cases from Marylebone, 148 came from within the 400 yards area.

METEOROLOGY AND ZYMOTIC MORTALITY FOR LONDON, 1901.

I prepared *Plate* III. in the early part of 1902 to demonstrate that, but for sewer-gas, epidemics of foul-air disease, especially in its more virulent types, would be almost unknown in London, a proposition which I had put forward in many forms in previous years. The figures are those of the Registrar-General.

The lowest curve shows the course of the deaths that occurred weekly from Zymotic in London; the figures under the line show the deaths from Small-pox included in the total. I regard these small-pox figures as most significant. They always seem to me to bear somewhat the same relation to that black mountain of death and the small-pox epidemic of 1901–02 (amounting to 9,659 cases), which the tiny streamlet bears to its mountain and the full flowing river which it ultimately becomes; but for the mountain there would be no streamlet source and no river. The other curves in order upwards are those of the average weekly temperatures, the total weekly rainfall in inches, and the sum of miles weekly of wind.

Between 54 degrees and 58 degrees I have drawn a straight line which I have called the danger line. I hope to explain more fully later on how it is that, when the temperature rises above that line, ventilation stops and sewer-gas is developed.* Meantime note that, corresponding to the rise of the curve above the danger line, we have a rise in the curve of the zymotic deaths. Note also that the deaths touched the very high point of 531 for one week that year, and that the temperature was generally above the average temperature as shown by the dotted curve for each corresponding week in the previous 50 years. The temperature curve may be regarded as the positive element in this demonstration. But it is subject to the negative influences of the rain and the wind curves, and it will be noted that in the year quoted there was little rain and the wind was generally below the average.

The curves therefore indicate a combination of meteorological conditions which were bound to produce sewer-gas of a very bad quality in the sewers by the middle of July, with the result on the death curve already pointed out. But why that depression in the death curve on the 10th of August? The rainfall on the 27th of July and the wind on the 10th of August are, one or both, apparently the cause of it. It is very material to the success of my demonstration that the depression is there and can thus be explained. On the added strength of this demonstration, I had no hesitation in claiming, at the time, that if we would only prevent sewer-gas, as we could easily do, we might expect to prevent 50% of our zymotic cases.

It may be as well if I just explain here once for all that if I say, or imply by anything I say, that sewer-gas causes disease, I do not mean that it does so specifically but indirectly and generally through lowered vitality.

THE RECORD RAIN OF 1903.

Plate IV. shows the prevention of sewer-gas, in an unusually large degree, as having actually resulted in a reduction of 50% of zymotic deaths last year as compared with the average of the previous ten years. As in the case of the previous diagram the curves in this series are taken from the returns of the Registrar-General and refer to London only.

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* See page 144.

Curve B shows the average course of the deaths from preventable diseases as registered weekly for the twenty weeks numbered 22 to 41 in each of the ten years ended 1902. The space included between the base line and the curve B represents the average volume of preventable deaths which occurred in this series of weeks in each of the ten years, the numerical value being 6,041. Therefore the number of deaths which took place in London in this series of weeks during the ten years ended 1902, and which were pronounced by the medical profession to have been preventable, reached the enormous total of 60,410.

Curve C shows the death course of preventable disease for the corresponding series of 20 weeks in 1903. The space between the base line and the curve C represents the volume of preventable deaths which occurred during these weeks, the numerical value being 3,499.

The numerical value of the difference between the death columns as traced by the curves C and B respectively is therefore 2,542.

Wherefore it follows that of the 60,410 deaths which were registered as preventable, on the highest medical authority, the very large proportion of 25,420 were preventable and that in no vague or official sense but really and truly preventable. Or, if we take the 13 weeks numbered 25 to 37, the reduction is just over 50% of the 10 years average of these weeks respectively.

Now I will show why I claim that this reduction was largely caused by the record rainfall of last summer preventing in an unusual degree the formation of bad sewer-gas.

As before, note the danger line L. Note also that the temperature curve runs well within the danger zone from the 25th to the 35th weeks inclusive. But the death curve C does not rise in sympathy therewith. This is explained by a comparison of its course with the courses of the wind curve K and the rainfall curve G. In the 25th week the temperature suddenly rose to 59·6, and in the next week to 65·2 degrees, dropping slightly to 63·6 degrees in the 27th week. The evil effects of these high averages were however neutralised by the extraordinary rainfall of 3·73 inches (curve G) in the 24th week and the good winds in the 26th and 27th weeks and so all along the line to the 32nd week, the increased danger which the high temperatures threatened being continuously averted either by the heavy rainfalls or the increases in the amount of wind. After the 32nd week the death curve C takes an upward sweep, reaching its highest point for the year in the 36th week when the deaths rose to 279. This maximum it will be noticed corresponds with a weekly temperature of 62·9 degrees, accompanied by an insufficient counteracting force in the rainfall and wind.

In all this the degree of correspondence between the courses of the curves representing the active and counteractive forces on the one hand and the course of the death curve on the other is seen to be too marked to avoid the conclusion that the incidence of medically preventable death will be light when the meteorological phenomena are unfavourable to the production of sewer-gas. But to confirm this conclusion I have taken for comparison the case of 1899, a very bad year for zymotic deaths. In the 31st week alone, as you will observe, there occurred 648 deaths as against the ten years average of 498 and the 1903 figure of 148.

These are sensational figures. But who took any particular note of them at the time ? They caused no scare. Of course I am not recommending scares. Foul-air disease of any kind is clearly not a matter that will justify scares. It only demands, and demands imperatively, that practical measures be taken that will prevent foul-air. I am only now drawing attention to the remarkable calmness with which abnormally high zymotic rates were passed over and the consternation and disturbance which the comparatively few cases of small-pox caused in 1901.

But if my contention is right we should find that the weekly temperatures ranged high and the rainfall and windage low in 1899 ; and this we do.

The temperature or dotted curve D follows a course of maximum danger, whilst the dotted curve F shows that the rainfall was almost *nil* and practically useless as a counteractive, and similarly with the dotted wind curve H.

As in the case of 1901, shown in the previous *Plate*, we have the depression in the centre of the death mountain—see the 32nd week— ; and again we see that this check in the fierceness of the death onset is explained by a slight drop in the temperature curve D in conjunction with an increase in the wind to a good amount on the 30th and 31st weeks and an increased rainfall in the 30th week.

HIGH SHAFT 86FT. FROM DWELLING HOUSE.

Two fallacies I must just mention. It is a fallacy to assume that sewer ventilation is analogous to the ventilation of mines; there is a similarity, but there are very different conditions to be dealt with. It is a fallacy to suppose that, if sewers are laid according to the best mathematical formulæ and provided with air shafts in sufficient proportion, no dangerous gases will be developed. It is seldom practicable to get such sewers; but, assuming the practicability, there are certain atmospheric conditions under which even perfectly laid sewers must develope serious danger; under such conditions, for example, as obtained in 1899 and 1901, and which in fact obtain in a greater or less degree during some part of every year, during which there can be no such thing as natural ventilation.

But I have found that the worst of all the fallacies is the high shaft fallacy. It is claimed that it is better to discharge sewer-gas at a high level than at a low level. This however raises quite a false issue; the real point is, that it is contrary to the Act of 1875 to discharge sewer-gas at any level that will be dangerous to health.

Plate V. represents an actual case of nuisance and danger from a high shaft. According to the weather conditions the sewer-gas sometimes enters the house by the chimneys and sometimes by the doors and windows. Note the distance from the top of the shaft to the ground floor windows—86ft.—and the position of the sideboard by the wall opposite to the window.

On or about the 5th of January, 1900, the smell in that room was very disagreeable and prepared plates were placed upon the sideboard and allowed to develope.

Plate VI. is a photo of the smell just alluded to. Need we wonder that deaths from diseases of the respiratory organs reached figures such as those shown on this *Plate*, when at that time such discharges as the photo represents were taking place from high ventilating shafts in many parts of London.

I ask you to note specially the mottled appearance. It was a time of cold and fog, when even well-clad people were liable to be chilled to the bone. The wonder is how so many escaped when such a large proportion had no alternative but to breathe such a polluted atmosphere in such a state of the body—an atmosphere to all intents and purposes charged with liquid sewer-gas. The foul warm sewer-gas, say 53 degrees, coming to the top of the shaft and meeting the cold air at say 30 to 40 degrees, condensed and floated downwards and the people had no option but to inhale it. That is what the mottled appearance means. It is easy to understand how death in the shape of influenza and consumption keeps such close company with those who have to live in such an atmosphere.

EFFECT OF RISE AND FALL OF SEWAGE LEVEL WITH HIGH SHAFTS.

It is of the utmost importance in practical sewer-ventilation to be able to take full advantage of the rise and fall of the sewage level. In cold weather, in a large number of cases, with a steady flow and no disturbance from side discharges of sewage into the sewer, the air currents would be entering by the top of the shaft as shown at A in *Fig.* 1, *Plate* VII. But there is no advantage in that as compared with a street level ventilator; for if the shaft be removed, the very same flow downwards would go on at the street level (*Fig.* 2).

But let the sewage rise as at B; then the shaft will be filled with foul air and a quantity will escape by the top of the shaft. When the sewage level again falls the shaft will fill with fresh air; but the foul air, which still remained in the shaft, to the full capacity of the latter, and did not escape, will simply be drawn back into the sewer again.

Or, take the case of C, where the rise in the sewage level is not so great as at B; the displacement of the sewer-gas is not sufficient to fill the high shaft; consequently no sewer-gas escapes, and therefore all of it is drawn down again into the sewer at the lowering of the sewage level.

But if we were to cut away these shafts at the street level, we would have not only the advantage of getting rid of all the bad gases that had been forced up to that level but, as soon as the sewage level began to fall again, the air from the outside would begin at once to go down into the sewer and so continue to do as long as the sewage level continued to fall. There would at times, however, be little or no oxidation of the gases in the sewer midway between the air shafts.

It is clear therefore that a sewer subject to those atmospheric conditions which prevent natural ventilation must, in the nature of things, become more rapidly dangerous when high shafts are relied upon for its ventilation than when street level gratings are employed.

INLETS AND OUTLETS.

Some engineers have advocated a system of alternate low level and high level ventilators, which they call "inlet" and "outlet" shafts respectively. From what has just been said it is obvious that this is a better plan than that of having the ventilators all of the high level type ; but would it not be better still to have them all of the low level type ? The answer must obviously be in the affirmative.

As to the inlet and outlet idea *Fig.* 1, *Plate* VIII., shows how absurd it is. Every discharge into a sewer moves the air in the crown of the sewer, and the direction of the movement of this air must be determined by the resistance. The least resistance will naturally be sometimes in the line of the low level gratings and sometimes in that of the high level outlets, and similarly with the reflex movement. Hence all low level and high level openings to a sewer are equally inlets and outlets according as they lie in the line of the least resistance to the forces acting for the time being.

INFLUENCE OF DIFFERENCE IN HEAD.

Fig. 2, *Plate* VIII., illustrates the point that the difference between the barometrical pressure at the head of a sewer and that at its lowest point is not necessarily a material factor in sewer ventilation. On this length of sewer there would be a difference of 57 grains per cubic foot between the weight of the air at its lower end and that of the air at the other end two miles higher up, and if there was nothing to disturb its operation this would cause a current to pass from the bottom end to the top. But we have already seen that any upward flow must be subject to constant and serious disturbance from side discharges and rise and fall in sewage level. The flow of air in the direction of the flow of sewage may as a force be valued in the same way.

Such forces as these, while they have their effect (and sometimes they have a very marked effect under certain conditions) are essentially incalculable forces. They should be used as far as they can help, and they must not be checked when they might be useful ; but they ought never to be relied upon.

INFLUENCE OF TEMPERATURE.

And now we come to a fact which at the same time explains all the difficulties of the problem and provides the key which will open the door to their practical solution.

You will remember that in *Plates* III. and IV. I assumed the danger line of temperature to be somewhere between 54 and 58 degrees. That is probably too high, but if we could get it universally recognised at even 58 degrees we would soon see such an improvement in the beneficent work of our public health service as would astonish even the most sanguine of our sanitary reformers.

In *Fig.* 3, *Plate* VIII., is depicted the actual condition of matters in a London sewer on a summer day. The highest temperature registered was 75 degrees and the lowest 57 degrees, whilst the temperature of the air in the sewer was constant at 52 degrees. In our illustration these figures are converted into grains per cubic foot. Thus we see that, while we had in the sewer an atmosphere which was constant at 544·67 grains per cubic foot, we had on the surface an atmosphere which weighed during the coldest part of the 24 hours only 539.40 grains (or 5·27 grains less) and during the warmest part of the day 523·18 grains (or 21·49 grains less). A sovereign weighs approximately 123·27 grains, so that the weight of something less than 6 cubic feet of sewer air would in the course of these 24 hours be heavier than 6 cubic feet of the outside air by the weight of a sovereign. Where is the law of Nature which justifies anyone in advocating the sufficiency of any system of natural ventilation under a continuance of such atmospheric conditions as these? You will now see the reason for placing the danger line of temperature between 54 and 58°.

For over forty years the controversy has been going on amongst engineers on the point whether high shafts or low shafts were the right system. As in the case of a previous point, this controversy has turned upon an entirely false issue; neither of them is right.

The low shaft, as we see, must fail when the atmospheric changes become unfavourable. How is this failure to be met? Surely of all the expedients ever proposed the high shaft is the most absurd and the most ill-starred. The money that has been wasted on it, the health and the lives that have been sacrificed to it, the beneficent work that has been prevented by it are, I am fully persuaded, altogether beyond the computation of any human faculty.

PRINCIPAL FORCES AFFECTING SEWER VENTILATION DURING THE SUMMER OF 1889.

We have seen how temperature affected ventilation on one warm day. By *Plate* IX., which will doubtless be familiar to some of you as it is quoted by Colonel E. C. S. Moore, R.E., in the two last editions of his valuable book, *Sanitary Engineering*, we are able to trace day by day, through the whole of the summer of 1889, the difference which the differences in temperature made between the weight of the air in the London sewers and that of the outside air, and what inevitably happened.

In March the air in the sewers was heavier than the outside air on one day only and then by only 1·18 grains, but the rainfall would more than counterbalance that. Towards the end of April the manufacture of sewer-gas would begin. In May, on two days only was there a pressure on the surface of the gratings, but the frequent rainfalls supplied fresh air in sufficient quantities to prevent the production of sewer-gas becoming very dangerous. In June, during the first six days, gas would form rapidly, but its bad effects would be modified by the rainfalls between the 6th and the 12th. For 22 days following, there being no rainfall, the manufacture of sewer gas went on uninterruptedly and a highly dangerous development was reached, gas of the worst description being now contained in the sewers. On the 27th June, two workmen went down a sewer in Stamford Street, Waterloo Road, and nearly met their death by the fumes of the sewer gas. When rescued, the men were unconscious, and one of them remained in that state for nearly an hour.

Here is a proof that very bad gas had been formed by the date named. How was it to be got rid of? Flushing now would only hasten the catastrophe, by driving the gases into the streets and houses. The rain came and did the flushing. Rain it will be seen fell on ten successive days from the 8th to the 18th of July, and the sewage level rose so that the bad gases which had been formed for 22 days were driven out and mixed with and vitiated the atmosphere. Shortly after the discharge of this volume of sewer gas an epidemic of typhoid occurred in the West End of London, and, on the 19th August, Lord Granby questioned the President of the Board of Trade as to the prevalence of typhoid in this district. The connection between the two phenomena is too close to be ignored.

REEVES APPARATUS.

Having thus considered the principal fallacies which entangle the sewer ventilation problem and the action of the principal meteorological forces which affect its natural operation, the way is now clear to submit a remedy. The remedy is simplicity itself; it may be stated thus:—

Never allow sewer gas to form.

The mother of all the sewer-ventilation fallacies is the initial mistake of allowing sewer gas to form. Prevent the formation and the whole brood of pestiferous fallacies which infest the problem will instantly disappear, and with them all the difficulties not only of the sewer ventilation problem but of the whole problem of sewage disposal. The remedy, in practical operation, is a method of obtaining that "full, free and unceasing ventilation" which Sir Robert Rawlinson said was the great *desideratum.*

Here let me say that, when I use the term "sewer-gas," I refer to air which has been polluted in a greater or less degree by admixture with the gases of sewage decomposition. By the term "sewer-air" I mean the air contained in a sewer, whether pure or in whatever degree polluted; and by "sewage-gas" I mean the neat gases of sewage decomposition.

Now sewage gases are always being evolved from flowing sewage. In the case of recently formed sewage, even when flowing through imperfect sewers, the amount of sewage-gas given off from (say) a square foot of surface in any given second of time is very minute in proportion to the whole surface. If then sufficient atmospheric oxygen is continuously supplied throughout the entire sewer, the sewage-gases are easily oxidised as they evolve, the sewer-air does not become polluted, and therefore sewer-gas does not form. Sewer-ventilation may therefore be defined as the continuous oxidation of the sewage-gases. Oxygen must be supplied in sufficient quantities, it must be supplied unceasingly, and it must be supplied freely; by freely I mean some method that will not interfere with the free play of any of the forces in a sewer having any tendency to supply oxygen in the form of atmospheric air; in other words it will be bad economy if any mechanical force is introduced which acts at any time in any very serious degree in opposition to any of the sewer forces.

Undoubtedly the cheapest natural way of getting the largest possible quantity of atmospheric oxygen into the sewers is by means of street-level gratings; but we have seen that, owing to temperature especially, the largest possible is often inadequate and sometimes absolutely *nil*, and also that the substitution of high shafts for street level gratings will hinder rather than help such natural ventilation.

The practical and well-tried remedy by which this inherent defect in natural ventilation has been overcome, and to which I now draw your attention, may be described as follows :—

Natural ventilation, as far as this is attainable, having been provided for by means of street level gratings, an apparatus (*Plate* X.) is fitted in certain manholes which are selected for the purpose after the local conditions have been considered. The covers of these, and indeed of all the manholes, are of course to be open gratings of any usual pattern.

By means of the water supply A, the reevozone, with which the large container B is charged, is automatically liquefied and delivered continuously in any required quantities on to the mixing disc C. Here it is mixed with the necessary quantity of acid, supplied, also continuously, from the smaller container D. Nascent oxygen, a powerfully oxidising gas, is thus generated, and also a strong permanganic liquid is produced. The latter descends from the mixing disc on to the cooling cylinders E which are placed underneath the mixer C.

The strong permanganic liquid, as it trickles from the lip of the mixing disc, is beaten up into a very fine permanganic spray or mist by the action of the sprayer F, which is shown just over the cooling cylinders.

With this strongly oxidising gas and mist the ventilation shaft is kept supplied. Hence, when the current is naturally inwards, atmospheric air entering by the grating goes down into the sewer charged with nascent oxygen and permanganic mist, both of which add greatly to its power to oxidise organic impurity. And when, on the contrary, the pressure within the sewer forces the sewer air upwards, the latter not only escapes freely by the grating but in an innocuous condition, having been completely purified in its passage through the atmosphere of permanganic mist and nascent oxygen.

By the action of this apparatus also currents of atmospheric oxygen are induced downward through the gratings, even under those meteorological conditions when, in accordance with the laws governing the action of gases, sewer ventilation, which is wholly dependent on natural forces, must become inadequate and even sometimes fail altogether.

The permanganic mist, mixing with the sewage and acting as an antiseptic (to such an extent, at least, as it may not have been exhausted on the sewer air), lessens the evolution of gas from the sewage. The perfect ventilation which this system secures also acts as a preventive of the evolution of gas from sewage, because putrefaction is less rapid in fresh air than in foul. The impure air from the streets is vitalised in its passage down the manhole. The present method of supplying air vitiated by street exhalations in dry warm weather, when sewer ventilation is most wanted, must often produce little or no result, sometimes even a bad result.

This system then is a Natural system up to the fullest limits of natural forces. It is Chemical and Mechanical where the Natural forces require to be supplemented to enable them to maintain without any break a complete oxidation of the sewage gases. By this system the sewer-air is kept fresh through and through the whole sewerage, and therefore no dangerous accumulations of sewer-gas can take place mid-way between the ventilators as we saw was the case with inadequate natural ventilation. To effect this through-and-through result it is not necessary that every manhole be fitted with an apparatus, but every manhole should have an open grating.

The water supply enters the apparatus by the double locking syphon water-seal, as shown at G, which thoroughly protects the water main from any back pressure of sewer-gas. This arrangement meets all the requirements of the Water Companies, and is an important feature in the system.

EDINBURGH INSTALLATION.

But a proposal, though demonstrably true, is itself no better than a fallacy if it be impracticable. Let me therefore give some particulars referring to three very remarkable cases from actual practice, premising that in no case has the method under consideration ever failed.

This apparatus is in use at Edinburgh on a main outfall sewer, which drains a large district of the town and also certain villages for seven miles above. The sewer is well built and graded, and delivers the sewage with a rapid flow, preventing any deposit; it receives discharges from distilleries, breweries, paper mills, chemical and other works, besides the drainage of a district having a population of nearly 200,000.

The surface gratings had all been securely closed, owing to the offensive emanations which came through them. The sewer was now without means of ventilation, and an outcry was immediately raised against the influx of sewer-gas into the houses under certain atmospheric conditions.

Ultimately Mr. Cooper, the late Edinburgh Engineer, decided to make experiments at three manholes with the Reeves system. Apparatus was set to work, and the grating in each case re-opened. Finding there were now no complaints, where formerly the gratings could not be left open without complaints, Mr. Cooper advised his authority to apply the system on a much larger scale.

The installation at Edinburgh to-day consists of fifty-three apparatus, of which forty-four have been running continuously since February, 1899.

During this time the reopened gratings have been entirely free from smell; and, although no district statistics have yet been drawn out to determine the effects of the system upon epidemics, it is certain that these have disappeared largely from the district affected.

When I say that the statement just read was submitted to, and approved by, Mr. Cooper and also by the then Clerk to the Water of Leith Purification and Sewerage Commissioners, you will understand that I am not submitting any impracticable proposal but one based on accomplished facts. May I just confirm this by quoting from the *Edinburgh Evening News*:—

> "Edinburgh Water Trust Meeting.—In the Minutes of the Works Committee it was stated that an application had been made by the Water of Leith Purification and Sewerage Commissioners, requesting that the Trustees would authorise a continuance of the supply of water for the Reeves Patent Ventilating Apparatus in use by the Commissioners; and also that in view of the success of the system and the public benefit obtained thereby the Trustees should make a reduction on the price charged. Sir Andrew McDonald explained that this ventilating apparatus was being used to prevent the escape of noxious gases from the drains in the streets."

Colonel Moore quotes some interesting figures relating to the currents of air in this section of sewerage from a paper read by Mr. Alex. Stewart (Mr. Cooper's assistant), which shows the serious practical difficulties that had to be overcome in this case.

SOUTHPORT INSTALLATION.

Here there was an almost perfectly flat sewer, subject to tidal influence.

On one section, 4,500 yards in length, low-level and high-level ventilators were tried without any success; 24 high shafts, fitted with gas furnaces, also failed to give satisfactory results; and all this notwithstanding that flushing chambers were fixed at intervals of about 200 yards. So acute had the position become that an eminent engineer was called in, and he submitted a scheme of improvement for the whole sewerage which was estimated to cost a very large sum. We offered to cure the evil, so far as the said section was concerned, for £260.

The following remark made in the Council, when the acceptance of our proposal was being discussed, is significant:—

> "Councillor Kennedy also called attention to the report on the Reeves system, and asked the Council to have sufficient faith in the wisdom of the Health Committee to pass it without discussion. A resolution in the minutes covered the Corporation and freed them from expense. That resolution was that the tender of Reeves Chemical Sanitation Ltd. be accepted, subject to the Company executing a contract providing that the apparatus, after having been used for twelve months, was, at the option of the Corporation, either to be accepted and paid for or rejected and removed by the Company at their own expense. He thought they might depend upon it that their Town Clerk was cautious enough and wise enough to draft an agreement out of which any company which was so disposed would not be able to wriggle; and as they proposed to hold the money until the new system had been thoroughly tested, they were perfectly safe."

When I can say that the account was paid in due course in such circumstances, I may well spare you any further statement regarding this case.

WANDSWORTH INSTALLATION.

Plate XI. brings us down to date. It represents a district in Wandsworth, roughly about 200 yards square. The London County Council main sewer runs along Garratt Lane, and has three connections with the Wandsworth Council sewer as shown. There is a Bone-works at X., which discharges its boilings into the sewer.

So recently as the 19th of February the inhabitants had an indignation meeting, at which the character of the district was described in the strongest possible terms. Meantime the Wandsworth Council had put the matter into our hands as regards the manhole marked B, in which we fixed an apparatus, opening the grating. All the other gratings (shown by round discs) had been closed, and the five high shafts (denoted by squares) had been blocked up with clay. The position at the present moment is that the high shaft at B has been taken down, the residents have requested that the others also be removed, and the Wandsworth Council have given instructions for a further installation at the manhole X. There is now no smell whatever at the open grating at B.

Now consider these facts about this case. Although there is a scarcity of houses in the vicinity, those in the district in question, numbering about 133, were reduced in rent from 12s. 6d. per week to 8s. 6d. per week; and yet 42 remained unlet. The loss of rent to the proprietors amounted to £780 per annum, and the loss of rates to the Council to £260; the annual cost of our system, even in this extreme case, will apparently be under £15.*

CONCLUSION.

Suppose the prevention of sewer gas to be continuous all over the London sewerage, what might we fairly expect as a consequence?

Say a reduction of only 15% of foul-air cases resulted. It is a low estimate to say that foul-air cases cost London £600,000 annually; yet a reduction of only 15% would be equal to a saving of £90,000. The cost of preventing the formation of sewer-gas would absolutely not exceed £50,000, probably it would fall considerably short of that figure. So that London would be £40,000 in pocket annually in cash alone under a system of perfect sewer-ventilation.

Our subject has strictly been that of sewer-ventilation and I have not touched upon the subject of outfall treatment at all, but the fact is that perfect sewer ventilation prepares the way to proper outfall treatment. It is, I submit with all deference, a great mistake to reverse that order. In giving evidence before the Royal Commission on Sewage Disposal, I made that a very special point. To attempt to solve the outfall problem before seeing that the innocuous transit of sewage through our streets is properly arranged for is like taking the second step first. The whole idea of the sewage disposal problem is the health of the people. It makes a mighty difference to the health of the people, as we have seen, whether sewage is conveyed to the outfall through fresh or through foul air sewers. Within common-sense limits it scarcely affects the health of the people by a single headache what the treatment at the outfall is.

---

* It is important to distinguish between the application of a Reeves apparatus in a case of this kind and the application of the Reeves system of perfect sewer ventilation to a system of sewerage. In the latter case the annual cost of maintenance would average about 5s. per apparatus for chemicals in high-class districts and about 10s. in those less favoured.

Moreover, when I am able to add that, when sewage flows to an outfall through fresh air sewers, the outfall treatment is greatly simplified, and that this again leads to efficient, economical and useful developments, it will be clear to you that the first step in the sewage disposal problem as a whole is sewer ventilation and this step should be taken before any other is attempted.

I may not have succeeded to the extent I wished in placing clearly my facts for the importance of sewer-ventilation,—and I may not have sufficiently shown the fallacies besetting the subject, with the practical difficulties and troubles to which they have given rise,—but the fact of the remedy is surely incapable of being misrepresented. The remedy is so simple and obvious in its conception, and the continued success which has attended its application to actual working conditions of the severest kind for several years is of so decided a character, that its capabilities cannot be misunderstood.

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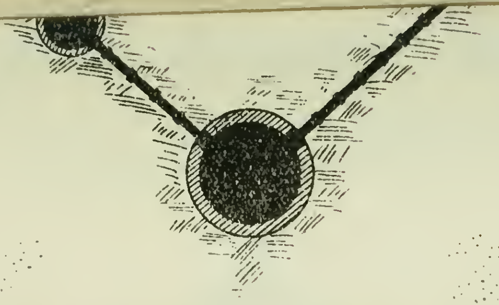


Fig. 2.

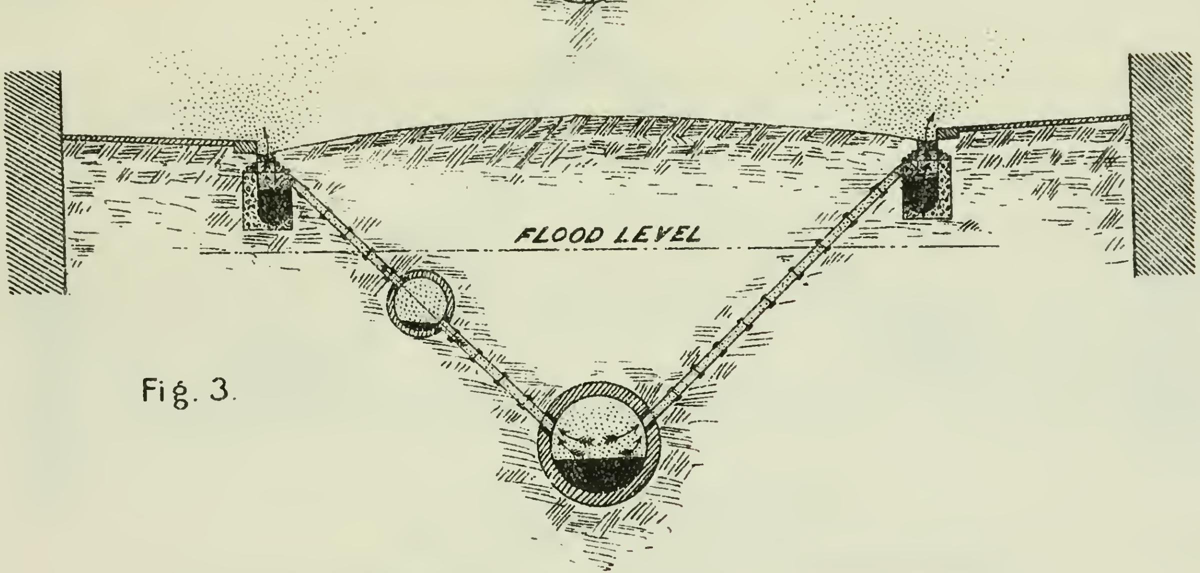


Fig. 3.

PLATE I.

PLATE I.

SYPHONING OF TRAPPED GULLIES AT WESTMINSTER.

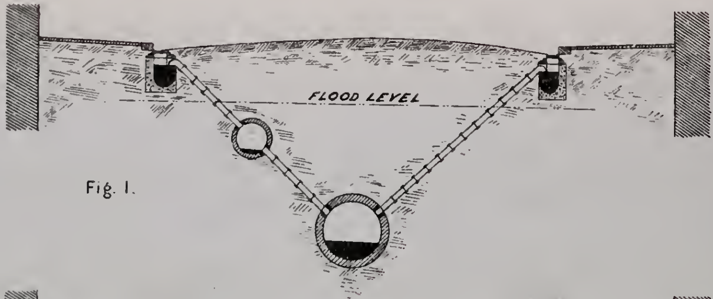


Fig. 1.

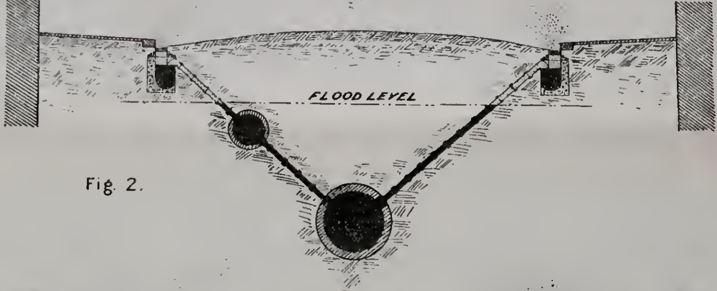


Fig. 2.

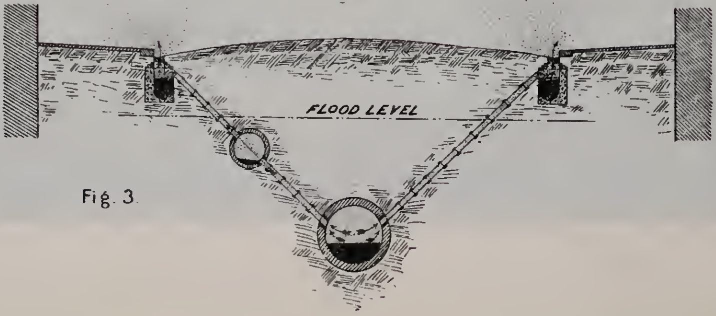


Fig. 3.

PLATE II.

FIG 1.

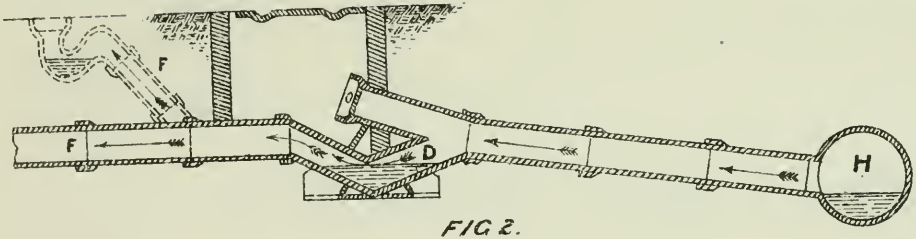


FIG 2.

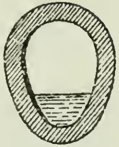


FIG 6.

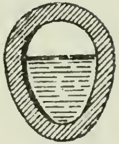


FIG 7.

SYPHONING OF TRAPS IN HOUSE DRAINS

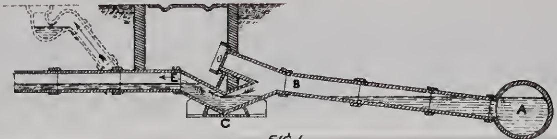


FIG. 1.

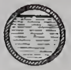


FIG. 3.

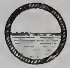


FIG. 4.

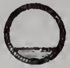


FIG. 5.

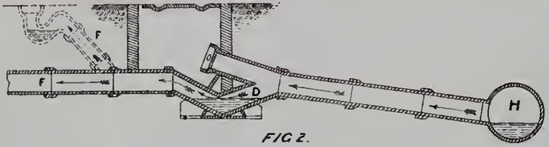


FIG. 2.

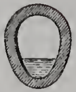


FIG. 6.

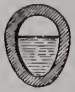
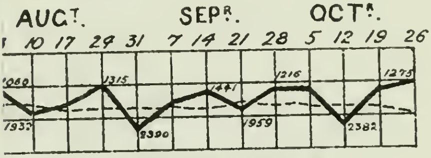


FIG. 7.

PLATE II.

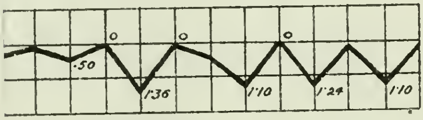
PLATE III.

TIC MORTALITY FOR LONDON ELATION TO THE PRODUCTION ER GAS



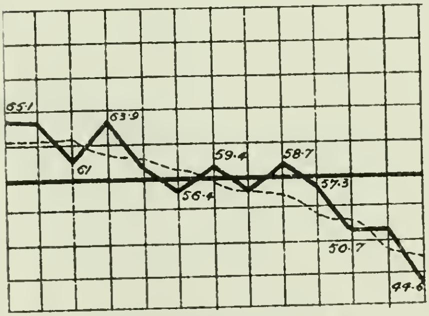
MILES PER WEEK.

e Average of 16 Years.



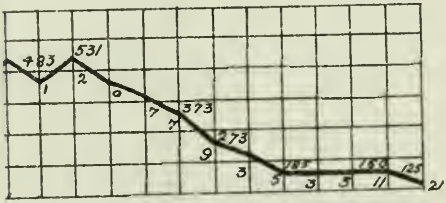
IN INCHES.

ainfall these weeks.



IN DEGREES FAH.

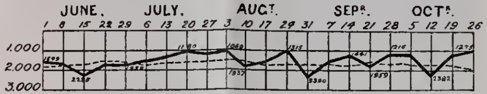
ve of the Average of 50 Years.



IC DEATHS PER WEEK.

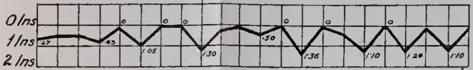
PLATE III.

METEOROLOGY & ZYMOTIC MORTALITY FOR LONDON DURING 5 MONTHS IN 1901 & RELATION TO THE PRODUCTION OF SEWER GAS



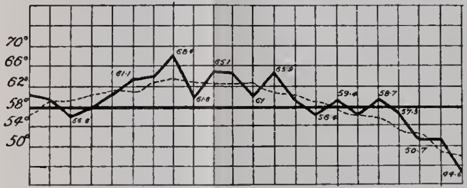
TOTAL WIND IN MILES PER WEEK.

The Dotted Line is the Average of 16 Years.



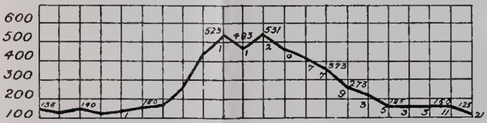
RAINFALL IN INCHES.

The O's mean no rainfall these weeks.



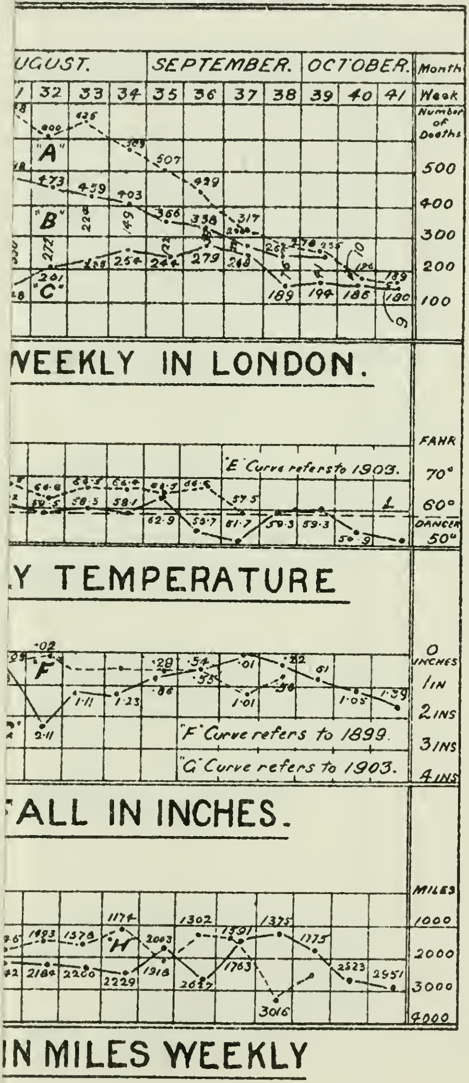
TEMPERATURE IN DEGREES FAH.

The Dotted Line is the Curve of the Average of 50 Years.



NUMBER OF ZYMOTIC DEATHS PER WEEK.

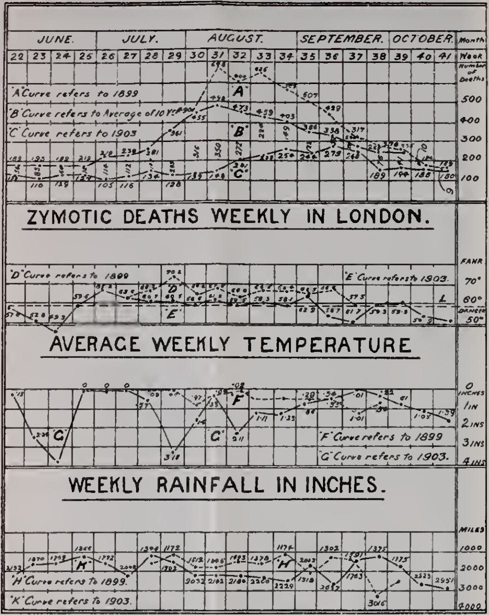
HE INFLUENCE OF SEWER-GAS
ER VARYING METEOROLOGICAL
DITIONS ——



"E" are formed in the ascending and
Curves "H" & "K" in the descending order
ly the effect of their mutual opposition
es.

PLATE IV.

DIAGRAM SHOWING THE INFLUENCE OF SEWER-GAS ON PUBLIC HEALTH UNDER VARYING METEOROLOGICAL —— CONDITIONS ——



SUM OF WIND IN MILES WEEKLY

NOTE

The Temperature Curves 'D' & 'E' are formed in the ascending and Rain Curves 'F' & 'G' and the Wind Curves 'H' & 'K' in the descending order of the figures to show more clearly the effect of their mutual opposition in relation to the Death Curves.

PLATE V.

ROM HIGH SHAFT.

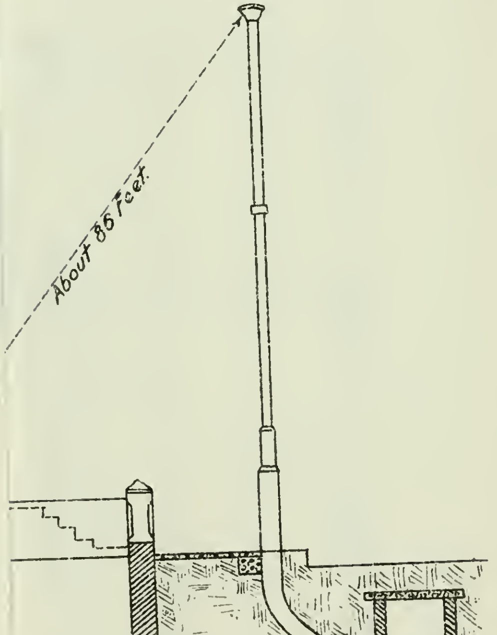


PLATE V.

NUISANCE FROM HIGH SHAFT.

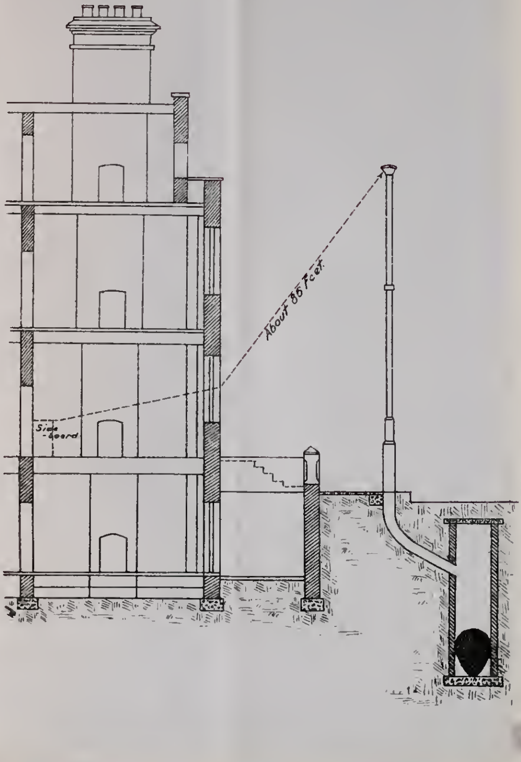
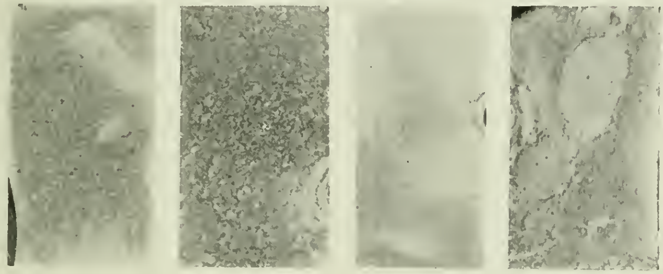


PLATE VI.

A BAD SMELL.

PHOTOGRAPH SHEWING THE DANGEROUS CHARACTER OF THE SEWER GASES ENTERING A DWELLING ROOM 86 ft. AWAY FROM A HIGH VENTILATING SHAFT.

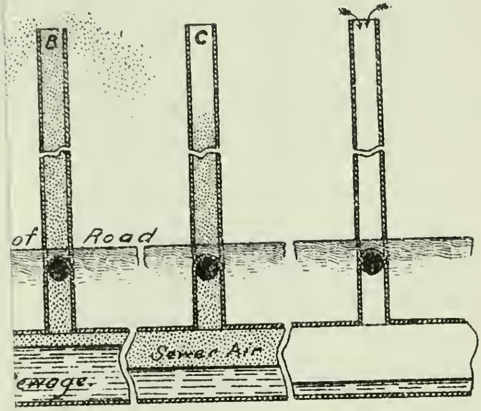


NATURAL SIZE.

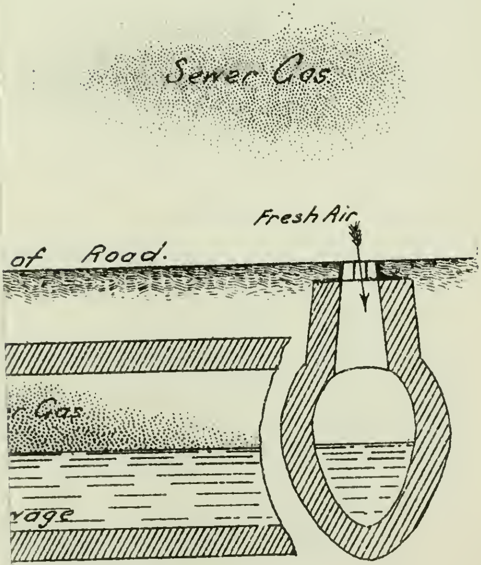
	1899.		1900.		
Week ending	Dec. 23rd.	30th.	Jan. 6th	13th.	20th.
Death Rate	29·9	35·2	37·1	33·3	26·9
Deaths from diseases of Respiratory organs	968	1,171	1,221	994	728
Above corrected Average	506	586	558	264	41
Deaths from Influenza	69	193	316	340	208

PLATE VII.

AND FALL OF SEWAGE
EVEL ——



H HIGH SHAFTS



H LOW SHAFTS

PLATE VII.

EFFECT OF RISE AND FALL OF SEWAGE —LEVEL—

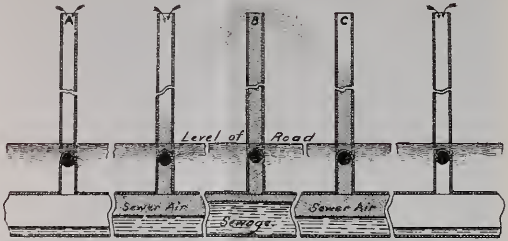


FIG 1, WITH HIGH SHAFTS

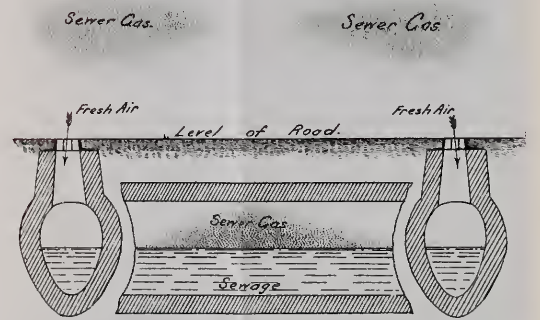
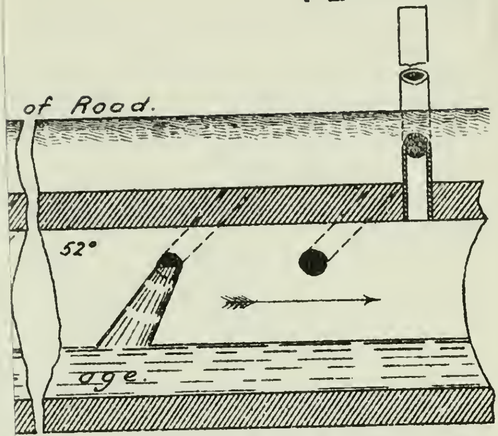
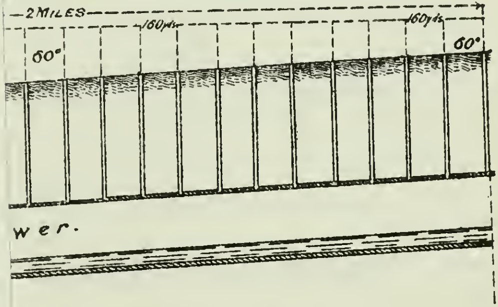


FIG 2, WITH LOW SHAFTS

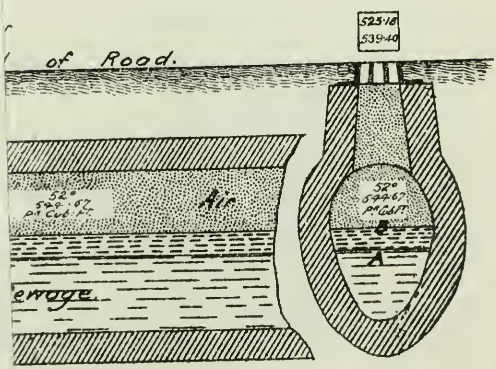
PLATE VIII.



SIDE DISCHARGES ON IN-
OUTLETS (*So Called.*).

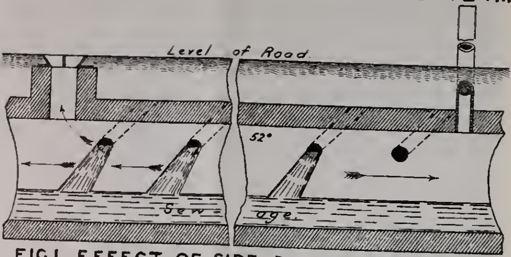


OF DIFFERENCE OF HEAD
IDS OF A SEWER.

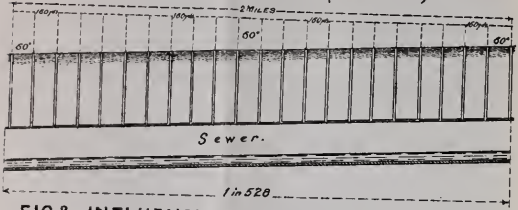


T OF DIFFERENCES IN
PERATURE.

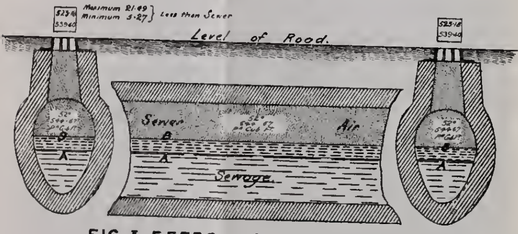
PLATE VIII.



FIG, I. EFFECT OF SIDE DISCHARGES ON INLETS AND OUTLETS (*So Called.*).

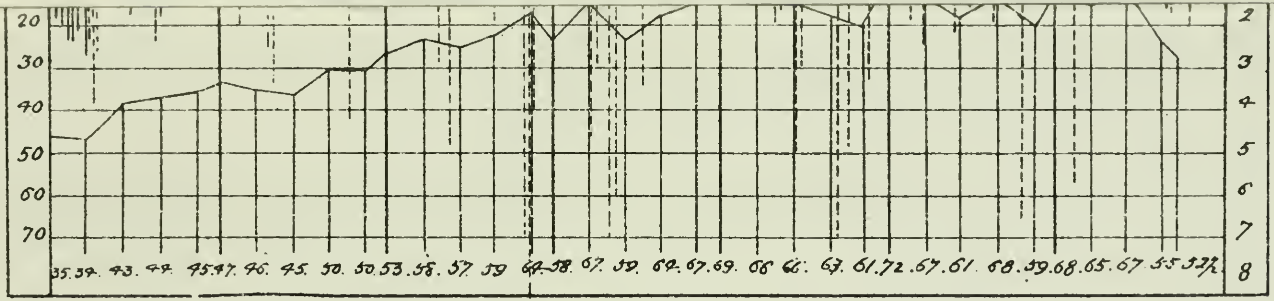


FIG, 2. INFLUENCE OF DIFFERENCE OF HEAD BETWEEN ENDS OF A SEWER.



FIG, 3. EFFECT OF DIFFERENCES IN TEMPERATURE.

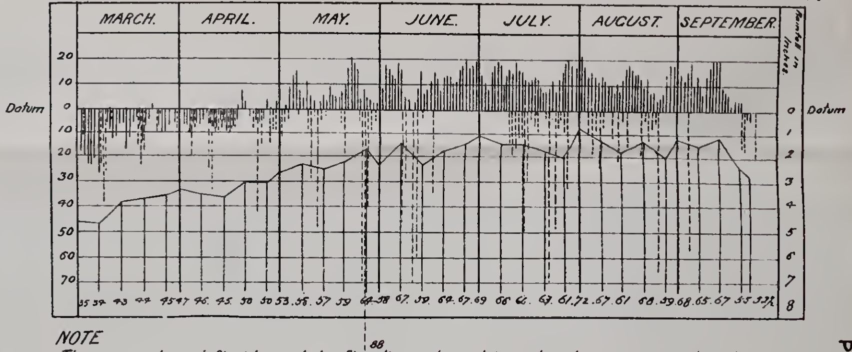
PLATE IX.



NOTE

The numerals on left side and the firm lines above datum, show in grains per cub: ft:, how much heavier was the air in the sewers. than that outside. The corresponding numerals and the firm lines below datum, show how much heavier was the air outside the sewers, than that inside. The dotted lines and the numerals on right side, show the rainfall in inches. The broken line and the numerals along the bottom show the average weekly temperature.

CHART SHOWING THE PRINCIPAL ATMOSPHERIC FORCES WHICH INFLUENCED SEWER VENTILATION DURING THE SUMMER OF 1899.



NOTE

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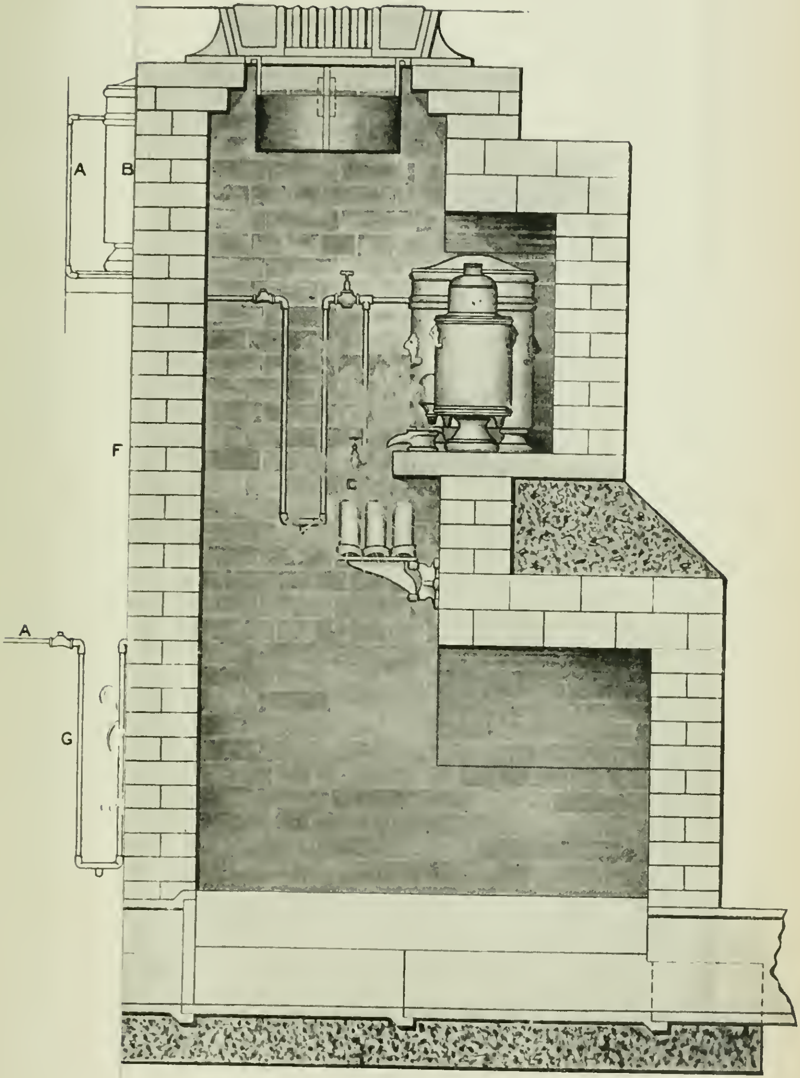
PLATE IX.

PLATE X.

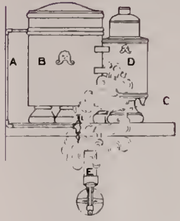
PPARATUS.



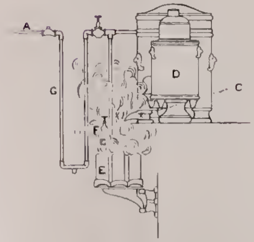
SIDE VIEW.

PLATE X.

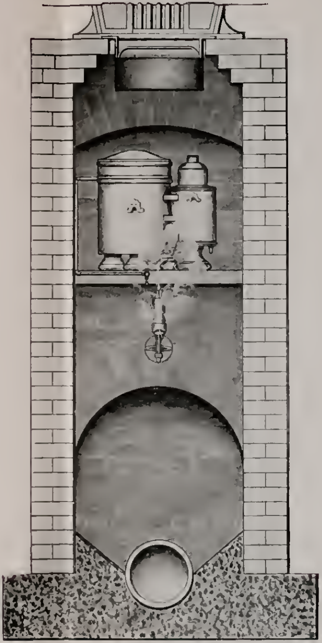
REEVES APPARATUS.



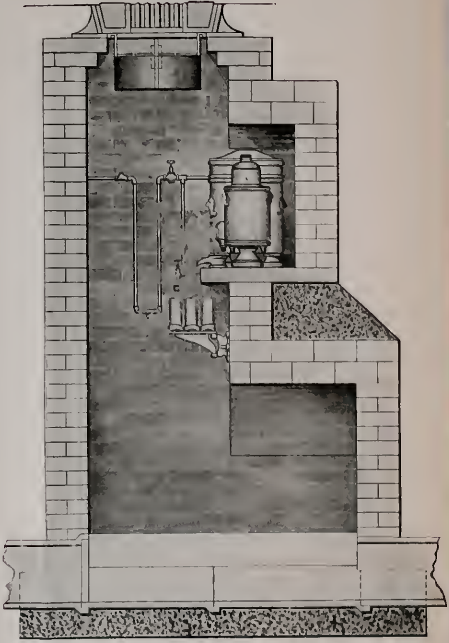
FRONT VIEW



SIDE VIEW



FRONT VIEW.



SIDE VIEW.

PLATE XI.

APPARATUS AT
SWORTH.

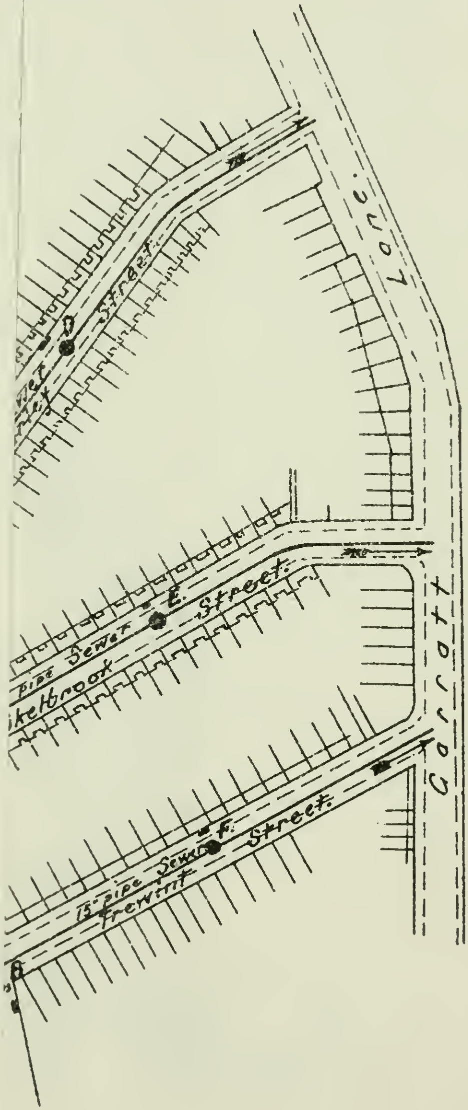
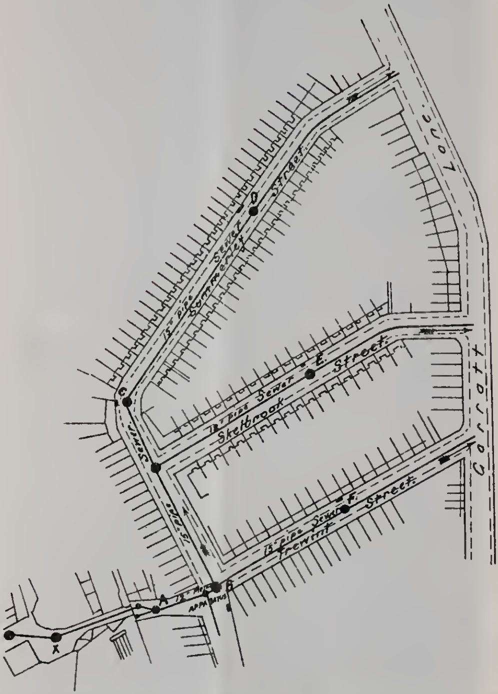


PLATE XI.

REEVES APPARATUS AT WANDSWORTH.



PAPER VII.

SALVAGE AND DESTRUCTION OF SHIPWRECKS.

BY

LIEUT. P. G. H. HOGG, R.E.

SALVAGE AND DESTRUCTION OF SHIPWRECKS.

THE work of removing or destroying shipwrecks is one of the duties of the Royal Engineers which few officers are called upon to carry out, and it is probably almost exclusively confined to the Calcutta and Rangoon Companies of the Indian Submarine Mining Corps. As however the work is very instructive, a short account of the wreck clearing recently done in Indian waters, and a description of the methods employed, may be interesting to the Corps at large.

The account will be divided into two heads which have no connection with each other;—(1) Raising wrecks. (2) Destroying wrecks.

RAISING WRECKS.

In the Hooghly and Rangoon rivers a large number of launches and cargo boats are always plying about, and it frequently happens that, owing to bad weather or collisions, some of them get sunk. The owner of any craft that has met with this mishap—if he considers it worth while—comes to the local Submarine Mining Officer and asks him to salve it.

Before being able to decide as to the possibility of the work, three data are essential:—(1) the tonnage of the wreck, (2) the depth of water in which it is lying, (3) its position with regard to traffic. On the tonnage of the wreck will depend the size and number of the lifting ropes necessary, and on the depth of water the length of such ropes; should the wreck be in a much used waterway, arrangements must be made with the Port Commissioners to regulate the traffic at that point and to prevent launches passing by at high speed whilst the work is in progress.

There are two methods of lifting wrecks:—(1) by patching up all holes and pumping out the water from the inside, (2) by making use of the buoyancy of cargo boats or lighters and lifting with the tide.

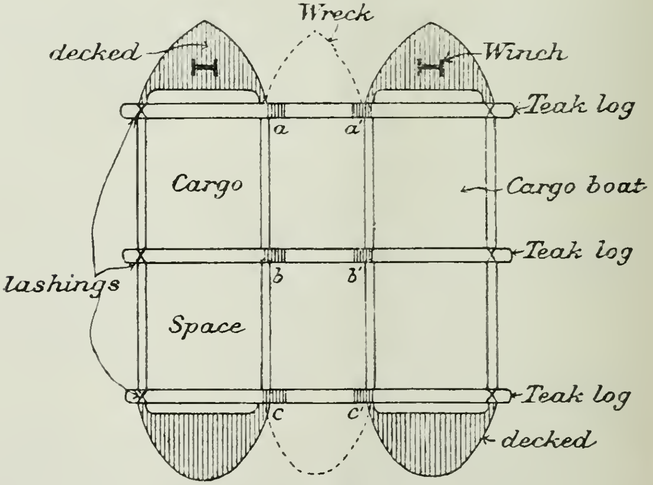
By Patching Holes and Pumping out.

The first method is difficult and requires a specially trained staff of divers; it would not be employed for the wrecks of launches, but only for those of larger vessels. It was once tried in Rangoon on the wreck of an oil-tank steamer, a pattern of vessel in which all the machinery is right aft, the rest of the ship consisting of large tanks for transporting oil in bulk. In this case, the after part, containing the engines and boilers, was cut off by charges of guncotton, and attempts were made to raise the rest of the vessel; but it was found that the shocks of the explosions had so started the rivets in the tanks that the inflow of water was as rapid as the progress of pumping out; hence the attempt was not a success. If hose charges of dynamite had been used, as described later on, the rivets would probably not have been shaken to such an extent, and the forward portion of the wreck might have been lifted.

Lifting by other Vessels.

The second method has been used in all other cases, and launches up to about 80 tons have been successfully raised in Rangoon.

The size of the local cargo boats varies, but taking a rough average they are 70 ft. long, 20 ft. beam and 10 ft. from keel to gunwale, with a buoyancy of 80 tons; they are undecked except for about 10 feet fore and aft. Two of these boats, coupled together (as in *Fig.* 1) with three teak logs of 2 ft. diameter, will make a



Sheet iron protection at a, a', b, b', c, c'.
Space between boats = beam of wreck.

Fig. 1.

CARGO-BOAT RAFT; PLAN.

raft capable of lifting the ordinary steam launch. The distance between the boats should be the same as the beam of the wreck, so the logs require to be about 60 ft. long; the two outer logs should rest just clear of the decked portion of the boats, and the centre one midway between them, all being firmly lashed where they cross the gunwales; at *a,b,c, a′,b′,c′*, a sheet-iron covering, 3 ft. wide, must be wrapped round the logs to prevent the wood getting nipped by the wire ropes. Hand winches should be fixed on the forward deck in each boat. When such a raft has been moored over the wreck operations can commence.

The lifting gear used is steel wire rope (4½-inch if procurable), which is preferable to chains as it is more handy and stronger for its weight; its one disadvantage lies in the possibility of its getting cut by the keel of the wreck, but this is rendered nugatory by the necessity of using a large factor of safety to allow for the suction of the mud on the wreck.

To lift the wreck three sets of wire rope slings have to be passed under it and fastened to *aa′, bb′, cc′* (*Fig.* 2); in these tidal rivers, the wreck will always be more or less silted up in the mud, so the only way to do this is to lift up the stern and pass the slings underneath it. Divers first go down and pass sufficient slings under the propeller shaft to bear the weight of the stern; these are made fast at *bb′*, and tautened up at low tide; as the tide rises the stern of the

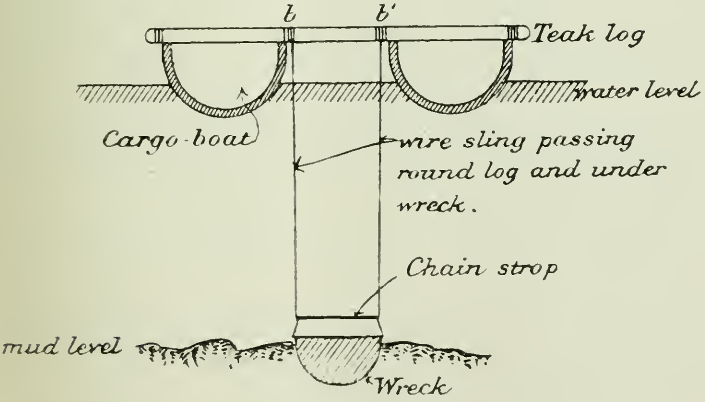


Fig. 2.

CARGO-BOAT RAFT; SECTION.

wreck is lifted up and, whilst it is in this position, the remaining slings necessary for the fore and mid portions are lowered down and pulled forward into their positions. When this has been done, the slings round the stern are slacked away at low tide, and preparations made for the final lift.

Some precautions must be taken to prevent the slings slipping during the lift. Securing the slings to each other along the length of the wreck was not found to be of any use ; owing to wreckage it was very difficult for a diver to pass along, and when he had done so he could not properly take in the slack of such longitudinal bracings. A more efficient method is to fix strops across the wreck. Each sling, after being placed in position, is slacked down a few feet; the diver takes a measured length of chain with him and, passing it round the sling, shackles the ends together. The length of the chain is calculated so that the strop is 1 foot less than the beam of the wreck at the point below it ; when the sling is tautened up the strop thus causes it to nip the sides firmly. When all the slings have been securely stropped everything is ready for the final lift. The above work takes between two and three weeks.

Now comes the exciting time. The working party get to work about half ebb tide, and commence tightening up all slings ; at low tide every sling should be hauled absolutely taut, care being taken that all are equally so ; as the tide rises the boats get deeper in the water, until their buoyancy asserts itself and they lift the wreck ; at high tide the raft is towed shorewards until the wreck grounds.

This procedure is repeated every tide until the wreck has been lifted to such a height that, when it has grounded at high tide, the falling tide will leave it high and dry. The work of salvage is then completed and the wreck is taken over by its owner.

The operation of lifting sounds simple enough, but in practice one often finds that accidents occur, especially if the wreck being dealt with is a heavy one. Sometimes the slings break owing to insufficient allowance being made for the suction of the mud ; or the wash of a passing launch may cause either logs or slings to break ; or the failure to tighten up all slings equally may cause them to part one after another as the strain comes on them. In Rangoon, on one occasion, whilst raising a cargo boat, the wash of a launch caused three huge teak logs to break like matchwood, fortunately without any of the working party being injured.

Much destruction was done to shipping in Rangoon by the cyclone of the 5th and 6th of June, 1902; during the ensuing four months three launches and one cargo boat were raised as above described, and were all used for work again. One of the launches was a twin-screw passenger ferry, 70 ft. long and 15 ft. beam; her stern was entirely covered with soft mud, the bow sticking up about 2 ft.; she lay in 4 fathoms. The divers got slings round each propeller, between the hull and the propeller shaft stays (which were of flat iron $2'' \times \frac{1}{2}''$); and the boat was successfully tipped up and slings passed under her. When she was raised it was found that the stays had carried away and the shafts were bent to a right angle, the propellers actually being on deck! The hull was not damaged, however, and with a few repairs she was fit for work again.

If the rise and fall of tide is small the work takes a long time, as in practice it is always found that the first three feet rise of tide are spent in tautening and stretching the slings. To obtain additional lift, it is a good plan to nearly fill the cargo boats with water when tightening slings at low tide and rapidly pump out as the tide rises; an extra lift of 4 ft. can be got in this way.

DESTROYING WRECKS.

The destruction of wrecks is a very different class of work to raising them, and is usually undertaken at the request of the Port Commissioners in order to remove those which are blocking up channels or fairways. The size of the wreck varies from ocean-going steamers sunk in the river channels to small craft sunk alongside a jetty, making it a foul berth for larger vessels.

Explosives used.

The explosives used are guncotton and dynamite. For breaking up large vessels, when charges up to 1,000 lbs. would be fired, guncotton is preferable to dynamite, as it is cheaper and can be easily made up into large extemporised charges. But when the work is of a more delicate nature (if one can use the word in dealing with high explosives)—such as the cutting off of certain defined parts of a wreck or the removing of snags—dynamite should be used, as it is plastic and can be packed up in canvas hose; and the charges thus made can be wound round whatever part of the vessel it is desired to remove, ensuring a good contact which is most essential.

The following is the usual method of making up charges:—

Guncotton in Bulk.—The weight of the charge having been determined, a canvas bag big enough to hold it is made; the detonator and primer are placed in a water-tight tin box, and the charge packed well round it. The mouth of the bag is closed by a wooden clamp (*Fig.* 3), grooved to admit the leads and fastened with two bolts and nuts; by applying indiarubber solution to the mouth of the bag before screwing up the clamp, a good water-tight joint is formed. For deep water diving, 10 fathoms and over, a coat of pitch is put over the charge; tar should be avoided, as it takes a long time to dry and ruins diving dresses.

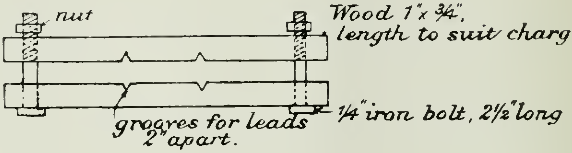


Fig. 3.

CLAMP TO CLOSE BAG CONTAINING GUNCOTTON.

Guncotton in Hose Charges.—When a long charge is necessary, as is often the case for breaking up the keel or gunwale of a vessel, the guncotton is packed in a 4-inch canvas hose. Such charges should never exceed 10 ft. in length, or they will be too unwieldy for a diver to handle. For a charge over 5 ft. long, a primer and detonator at each end should be used. The ends can either be closed with clamps, as above described, or by means of a billet of wood, 6 inches long, roughly turned on a lathe to fit the hose. The billet should be cut in half and grooved to take the leads; when screwed up, smeared with glue, and well bound in the hose with spun yarn, a good joint is obtained, as the wood grips the insulation of the leads sufficiently to make the whole water-tight.

Guncotton hose charges are not very pliable, and should not be placed round any portion of a wreck presenting many angles, for absence of contact along the length of the charge will then greatly lessen its effect.

Dynamite.—Dynamite is usually made up into canvas hose charges as described above, but a smaller hose will suffice, either 1½ or 3-inch. The former will take about 1 lb. of dynamite per foot run, and the latter 3 lbs.; a 1½-inch hose charge will easily cut a 1-inch iron plate. No primer is required, only a detonator, which, however, must be well fitted into the dynamite. Care must be taken not to ram in the dynamite too hard, or the nitro-glycerine will come through the canvas and the charge will then be highly dangerous to handle. To pack the charge, use a wooden rod, such as a broomstick; never use a metal rod. In Calcutta, in 1903, a non-commissioned officer rammed a charge too hard and reported next morning that it had been "sweating in the night"; a little of the "sweat," put on a piece of clean blotting paper and hammered on an anvil, went off with a fine report, shewing that the nitroglycerine had come right through the canvas.

As dynamite disintegrates in water, it is advisable to treat all canvas hose with boiled linseed oil to ensure its being water-tight.

Firing.

All firing is done electrically, either with a battery or an exploder, the latter for choice, as it is far handier to move about; occasional tests should be taken with either, to find through what resistance it will fuze a detonator bridge.

A short description of some of the wrecks destroyed during 1902 and 1903 is given as an illustration of the actual work.

S.S. "Camorta."

This was a British India steamer, of about 2,000 tons, which was lost in the cyclone of May, 1902, while on her way to Rangoon. After two months she was discovered with just her two masts shewing out of water; she lay in 17 fathoms, in the direct route between Rangoon and Calcutta, her position being roughly 25 miles east of the Alguada reef, 40 miles south of the mouth of the Bassein River and 120 miles from Rangoon. Being highly dangerous to navigation, the Government of Burma ordered her masts and funnels to be removed.

In September a party set out from Rangoon in the R.I.M.S. *Dalhousie.* The monsoon, however, was still blowing and, on arrival at the scene of the wreck, it was found impracticable to lower the diving boats; so after an investigation of the wreck in the ship's gig, the attempt had to be abandoned. In February, 1903, a similar party again set out; by this time one of the masts had disappeared and the other was about 3 ft. above water.

The first thing to do was to find the sunken mast; after about two hours search, it was discovered 10 ft. under water. The diving boat was then moored over it and, after a little manipulation, a line was fouled round the stump (as sharks abounded, it was impossible to send anyone overboard with the line). A diver went down and reported the mast clear to within 10 ft. of the decks; he had a hard time of it as the ship was lying with a big list to starboard and the mast was covered with barnacles.

Charges were prepared of 40 lbs. of guncotton, made up in two square charges of 20 lbs. each; these were heavily weighted, and so fastened together that they could be slipped over the mast and lowered away till they jammed, thus ensuring close contact (*Fig.* 4).

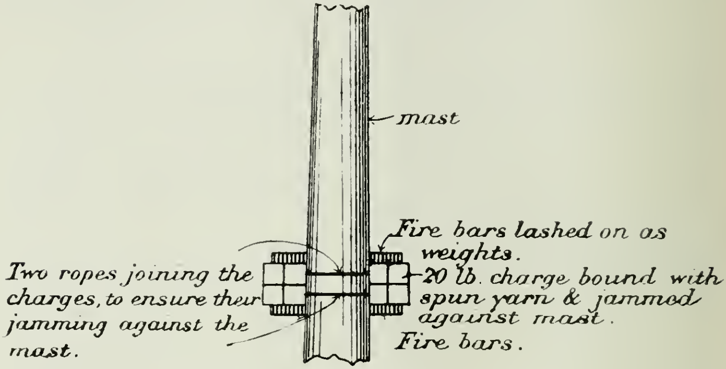

mast
Fire bars lashed on as weights.
20 lb. charge bound with spun yarn & jammed against mast.
Fire bars.
Two ropes joining the charges, to ensure their jamming against the mast.

Fig. 4.—*S.S.* "*Camorta.*"

PORTION OF MAST, SHOWING CHARGES JAMMED AGAINST IT.

The diver took them down 45 ft. and lowered them away another 20 ft. till they jammed; the charge when exploded completely severed the mast.

After this, sweeping was done to see if the funnel was still in position; but no traces were found, and it was concluded that it had gone overboard in the gale. The remaining mast was then blown up with a similar pair of 20 lb. charges; and, after much sweeping and searching, the smallest sounding got was 66 ft. below low water; this being sufficient the party returned to Rangoon.

In connection with this, it would be interesting to know of other occasions where R.E. officers and men have gone to sea to carry out a purely naval job.

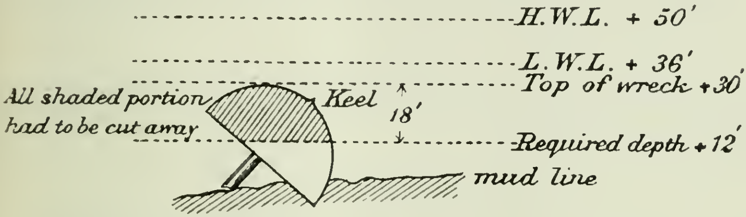
S.S. "*Calcutta.*"

This was an iron screw steamer, which sank in 1878, almost alongside the Babu Ghat jetty on the Hooghly. Some years ago, two or three unsuccessful endeavours had been made to remove it with gunpowder, but these had to be abandoned on account of the vibration set up.

In May, 1903, a further attempt proved effectual, and on the 31st of October there were 24 ft. of water over the wreck at low tide.

The ship was 250 ft. long and lay in 50 ft. of water at high tide; at low tide, however, there were only 6 ft. over her, and the Port Commissioners asked to have her cut down so that there should be 24 ft.

Examination proved that the ship must have turned over (*Fig.* 5),



Wreck turned nearly over, kept in position by broken wreckage of mast and funnel. Owing to wreckage, the actual beam and depth from keel to main-deck could not be determined.

Fig. 5.—*S.S.* "*Calcutta.*"

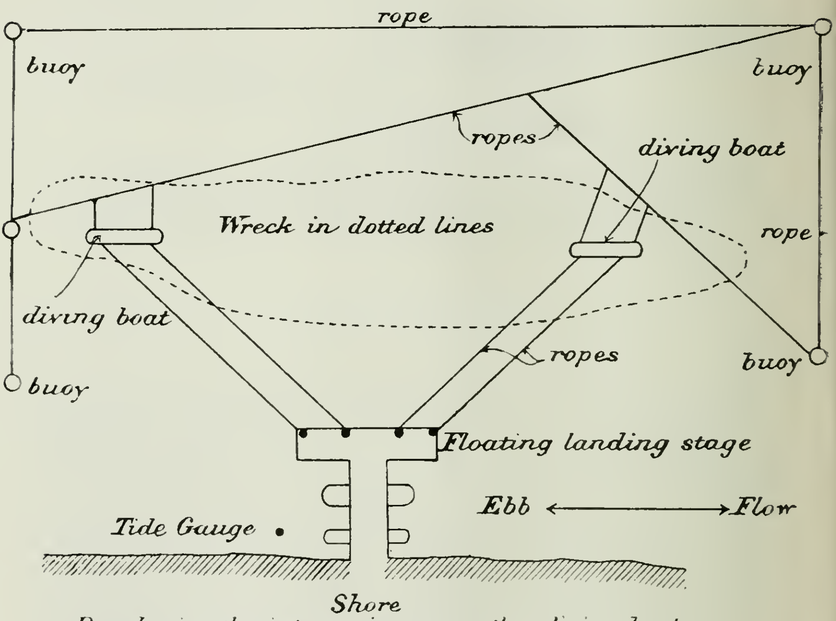
SHOWING WRECK TURNED OVER.

so that in this case it was the hull which, being above the required depth, had to be removed. The work was rendered tedious by the fact that the High Court of Calcutta was within 100 yards of the wreck, and its shaky condition owing to the earthquake of 1897 necessitated the charges not exceeding 10 lbs.; and eventually, owing to an outcry in the town that windows were being broken, plaster tumbling off the ceilings, etc., they were reduced to 5 lbs.

Dynamite was used throughout, 8,000 lbs. in all. The charges were mostly made up in $1\frac{1}{2}$-inch canvas hose; this took roughly 1 lb. per foot run, and the explosions made very clean cuts in the ship's plates, which were $\frac{3}{4}$-inch iron. To cut down the gunwale and the keel, which were stronger than the hull, charges were made up in 3 inch hose in 4-ft. lengths. With these small charges, the work consisted of systematically cutting away plate after plate; in fact, a horizontal section of the ship, varying in depth up to 18 ft., had to be shaved clean away. Luckily there was deep water round the wreck, so that there was no necessity for picking up the pieces, which were left where they fell.

About the beginning of September the demolition was practically finished and all that remained to be done was to cut off the snags that stuck up, chiefly bits of engines; these numbered about a hundred.

The ordinary method of sounding was useless in detecting these snags, so a regular sweep was organised. There were five buoys round the wreck and these were roped together; by means of cross ropes, which could be altered as found necessary, the two diving boats could sweep completely over the wreck (*Fig.* 6). In each boat there was a piece of gas-piping, 20 ft. long, to the ends of which were attached ropes marked off in fathoms and feet; according to the state of the tide, shewn by a tide-gauge ashore, the pipe was let down to the level of 24 ft. below low water, and the diving boat hauled it across the wreck until it caught a snag. A diver then went down and fixed the charge. In this way as many as 10 charges could be fired from each boat during a favourable slack tide. On



By altering the intervening ropes the diving boats could be pulled where wanted.

Fig. 6.—*S.S.* "*Calcutta.*"

ROUGH PLAN, SHEWING METHOD OF SWEEPING FOR SNAGS.

October 31st the last snag was removed and the job was completed.

Nothing of particular interest occurred outside the work, except one day when a visitor jumped on top of two charges which were lying covered up with canvas at the bottom of the dinghy; however no disaster took place, as might have been expected.

CARGO BOATS.

Two of these were blown up in Rangoon in July, 1902. Guncotton in square charges was used and the work presented no difficulty. Being close to the shore small charges had to be used; but the first one, about 40 lbs., caused such a tremor in the town that everyone thought it was an earthquake and it was reported as such to the Calcutta press.

S.S. "Deepdale."

This was an iron steamer, of about 3,000 tons, which, on leaving Calcutta in August, 1902, had struck the mud and turned turtle in a few minutes. She sank in Pir Serang Reach, eight miles below the city, and was highly dangerous to navigation. The Port Commissioners first asked for the masts to be cut off, and this was done in September by square guncotton charges; in November, however, they asked further for the entire ship to be removed.

Divers were sent down to report, and it was decided to place two large charges in the midship hold. Two old wooden pear-shaped mine cases were filled respectively with 570 and 600 lbs. of guncotton, placed 60 ft. apart, and fired simultaneously; this shattered the ship, but some large pieces were left upstanding, and these were removed by two square charges of 400 lbs. each.

After this very little remained and it was expected that the wreck would sink in the mud. In May, 1903, however, soundings showed that the mud was silting round the wreck and more removal was necessary.

Divers examined the place, and reported that a corner of the engine room was sticking up beyond the required depth of 26 ft. below low water. At the request of the Port Commissioners a charge of 200 lbs. of dynamite was fired in it; this settled the engine room, but at the same time heaved up above the required depth small portions of the wreck, consisting of pieces of bent plates and stanchion rails; these were removed by 3-inch dynamite hose charges, 10 ft. long, twelve such charges being necessary.

As the wreck was in the middle of the river, and both ebb and flood tides were strong, the following method was adopted for detecting snags :—At low tide a couple of launches swept over the wreck with a weighted bamboo rod, lowered over their bows to the required depth. On hooking a snag, a bare-skin native diver was sent down to fasten on it a grass rope, the end of which was buoyed ; at high water slack the diving boat moored on to the buoy and, hauling up taut, used the grass rope as a down line ; directly the charge was laid, the boat moved on to the next buoy.

The total amount of explosive used was :—Guncotton 2,750 lbs. and dynamite 560 lbs.

The removal of the masts in the first place was a waste of time and material, as their wreckage made it difficult for the divers to lay the two big charges which by themselves would have broken off the masts as well as smashing up the ship.

PAPER VIII.

A NEW SYSTEM OF REINFORCED BRICKWORK AS APPLIED TO ABOVE-GROUND CYLINDRICAL WATER TANKS.

With Notes on Racquet Court Walls and Reinforced Brickwork Parapet Walls.

BY

MAJOR E. STOKES-ROBERTS, R.E.

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A NEW SYSTEM OF REINFORCED BRICKWORK AS APPLIED TO ABOVE-GROUND CYLINDRICAL WATER TANKS.

With Notes on Racquet Court Walls and Reinforced Brickwork Parapet Walls.

I.—CYLINDRICAL WATER TANKS.

The largest tank of this type so far constructed is one containing 25,000 gallons, its internal diameter being 23 ft. and its depth 10 ft. Although greater diameters and depths could no doubt be successfully adopted, it would perhaps be well, until further experience has been obtained, to limit the diameter to 35 ft. and the depth to 15 ft., giving a capacity of 90,000 gallons.

The design appears suitable for adoption in any locality where bricks or building stone of ordinary quality are available ; and the following description of a 5,000-gallon tank will apply with slight modification to reservoirs of any capacity within the above limit.

This form of construction should, in most places, prove decidedly economical, as there is no expenditure to meet beyond the comparatively slight cost of the iron and the ordinary local rates for brickwork, concrete and plastering. In contrasting this type of tank with one of similar capacity constructed entirely of iron, it will be seen that the amount of metal required to ensure the stability in the former is but small compared with that in the latter, which has to be made strong enough to admit of easy handling, and thick enough to compensate for any loss of strength through the action of rust. A reference to the calculations for a 5,000-gallon tank on page 175 will shew that for the bottom 12 inches (where the pressure of the water is greatest) a thickness of metal of $\frac{\cdot 23}{12} = \cdot 02$ inch, or one-fiftieth of an inch, will suffice for the reinforced brickwork tank; whereas probably at least $\frac{1}{4}$ inch, or twelve times this amount, will be required for practical reasons in the case of an iron tank. The capitalized cost of maintenance and the question of durability should also be taken into consideration, when comparing the two forms of construction.

The principle involved is the outcome of an idea to avoid the expense of centering, which forms a somewhat large item in the cost of tanks built of reinforced concrete unless it can be utilized two or three times over or can be arranged to work in for other structures.

There is much accumulated evidence to show that iron or steel is indefinitely preserved when in complete contact with cement or cement mortar, a chemical action taking place in addition to the mere mechanical protection afforded against damp and carbon dioxide. It may therefore be assumed that this type of tank should prove very durable.

The advantages of the design appear to be :—

(i.). Economy in construction.
(ii.). Saving of maintenance charges as compared with iron tanks.
(iii.). Rapidity of execution in comparison (*a*) with ironwork, which must be specially ordered, or (*b*) with simple masonry, which entails the handling of a far greater mass of material.
(iv.). Saving of space as compared with ordinary brickwork or masonry.
(v.). Suitability for either temporary or permanent water supplies.
(vi.). It lends itself to any desired degree of architectural treatment.
(vii.). It can be used for an elevated tank in combination with armoured concrete for the bottom.
(viii.). A flat or domical covering of reinforced concrete is easily applied.
(ix.). Should increased depth and storage capacity be required at a later date the necessary additional reinforcement can be provided without difficulty, whereas iron or masonry tanks are usually only suitable for the depth of water for which originally designed.
(x.). The calculations for the reinforcement are extremely simple.

DESCRIPTION OF A 5,000 GALLONS ABOVE-GROUND TANK CONSTRUCTED AT THE CORDITE FACTORY, COONOOR, INDIA.

A cylinder of $12\frac{1}{2}'$ internal diameter and $6\frac{1}{2}'$ high was built of brick in cement, 9″ thick, the greatest care being taken that all joints were properly filled in. The mortar consisted of 3 parts clean sharp sand to 1 of cement. The bricks, instead of being soaked in water in the usual manner, were immersed before use in a thin cement and water grout. Walls.

Pieces of telegraph wire 14″ long were built in radially at vertical and horizontal intervals, as shown in *Fig.* 1, *Plate* I, and *Figs.* 1 and 2, *Plate* IV., the wires in each course breaking joint with those in courses above and below. The circumference of the tank being 44′, forty-four of these wires were required for each of the 18 lower horizontal courses and 22 wires for each pair of the 8 upper courses.

Great care was taken to make the brickwork truly cylindrical, and as the work was carried up, a layer of cement plaster (1 cement, 3 sand), not exceeding $\frac{1}{4}''$ thick, was given to *inner and outer* faces of the wall and left rough (*Fig.* 2, *Plate* I.). On completion of the brickwork the internal water-tight coat of plaster (1 cement, 2 sand), $\frac{1}{4}''$ thick (making $\frac{1}{2}''$ in all), was put on, and both faces of the wall were kept thoroughly wet.

When the brickwork was well set and the radial wires secure, horizontal rings—$\frac{3}{16}''$ diamr. telegraph wire for the top of the walls, $\frac{1}{4}''$ to $\frac{3}{8}''$ diamr. iron bars for the lower portions—were made up in straight lengths on the ground, each length being hooked to the next (bent cold), as shown in *Fig.* 6, *Plate* IV. The total length of ring as laid out on the ground was the *actual* circumference of the brickwork (say 44′).

The bottom ring was then laid out on the lowest tier of radial horizontal wires, which were at once turned up as shown at A (*Fig.* 3) and tapped gently with a piece of wood into position. The second ring was then placed on the second layer of radial wires, which were turned upwards as before, the joints X, Y breaking joint with similar junctions of ring below. Joint B was then completed as shown in *Fig.* 4, the projecting ends of the lower radial wires being carefully turned down.

The lower horizontal rings were thus clipped to the wall at distances of 6″ throughout their length, and kept away from the wall by a distance equal to the diameter of the telegraph wire radials; the upper rings were clipped at 1′ intervals (*Fig.* 1, *Plate* II., and *Fig.* 2, *Plate* IV.). If care is taken in making the clip joints the horizontal rings are rigidly held in position and no tightening up at all should be required.

The ends of the rings (viz., X and Y) were then secured with two complete turns of telegraphic wire (making 4 wires at cross section in centre of joint) as shown in *Fig.* 5, *Plate* IV.

On completion of the external network the whole ironwork was carefully painted over with cement grout; and immediately afterwards a layer of cement plaster (1 cement, 3 sand), sufficiently thick to well cover all the joints in the wires, was laid on and well tapped into position, commencing from the bottom. A total of about 1¼″ thickness of plaster (including the original ¼″) should suffice, where the horizontal rings are of small diameter.

The thrust rail or girdle for the dome was next placed on the top of the wall (*Fig.* 2, *Plate* II.), and the construction of the dome proceeded with.

The cornices and ornamentation were the final operation.

In a dry climate it would be well to defer the inner watertight coat of plaster until a few days before the water is to be let into the tank.

So far, 9″ brick cylinders have been used in each case, but 4½″ brickwork could no doubt be used for small tanks if economy of space or materials were desirable.

The functions of the radial wires are as follows :—

(i.). To ensure the correct vertical spacing of the horizontal rings.

(ii.). To securely clip the rings to the brickwork cylinder.

(iii.). To ensure a space between cylinder and back of rings, in order that the cement mortar may be in complete contact with the ironwork and so save it from deterioration.

(iv.). To give additional strength where the rings are placed some distance vertically apart, and thus prevent the brickwork being blown out between the rings.

Dome.

The dome for this tank was constructed of reinforced cement mortar (1 cement, 3 sand), 2″ thick at springing and 1½″ at crown. The thrust is taken up by a rail 9 lbs. to the yard, bent to a circle of 13′ 3″ internal diameter (*Fig.* 2, *Plate* II., and *Plate* VII.), and placed in position on the centre of the wall.

The mud centering was supported by blue-gum uprights footed in sand boxes (*Plate* V.), a good proportion of sand being used in the upper surface of the mud plaster to prevent cracks.

To make the grill, a ring R_1 (*Figs.* 1 and 3, *Plate* VI.) for the manhole opening, consisting of a welded hoop of $\frac{3}{8}''$ bar iron, was first placed on the top of the centering. To this ring were hooked 8 primary radial rods of telegraph wire, the outer end of each being bound by fine wire to the thrust rail.

As soon as the 8 radials were secured in position, the remaining rings R_2, R_3, R_4, and R_5 were placed on the top of them and secured in position by thin wire. R_5 was laid above the bottom flange of the thrust rail.

Further radials, increasing in number from crown to springing (*Figs.* 2 and 3) were then hooked on to the rings from which they started, and tied with wire to the other rings they crossed in a sufficient number of places to keep them securely in position.

The mortar was laid in *thin* layers well rammed, commencing above the wall and working upwards.

When the dome was thoroughly set, the plugs were removed from the sand boxes, allowing the centering to subside gradually and uniformly. The centering was finally taken to pieces and removed through the manhole.

CALCULATION FOR HORIZONTAL RINGS.

The bursting pressure per lineal unit in a cylinder containing water is equal to the water pressure multiplied by the diameter. As this bursting pressure is resisted by the material contained in the sides of the tank at both ends of any given diameter, the resulting tensile (circumferential) stress per unit area equals half the bursting pressure divided by the thickness of the side wall,

i.e., if p = water pressure, d = diameter of tank, and t = the thickness (in this case of the reinforcement only, as the strength of the brickwork is neglected),

then

$$\text{the tensile stress per unit area of the bars} = \frac{pd}{2t} = \frac{p \times \text{radius}}{t}.$$

Taking the safe tensile strength of the horizontal bars of the tanks as 5 tons (equal to 11,200 lbs.) per square inch,

we find

the required area of the bars in any given vertical foot of the wall

$$= \frac{\text{the pressure for that foot} \times \text{radius of tank}}{11{,}200}.$$

The pressure on unit length of bottom foot ($5\frac{1}{2}'$ to $6\frac{1}{2}'$) of tank $= 6'$ (depth of centre of gravity) $\times\ 62\frac{1}{2}$ lbs. $= 375$ lbs.,
so that
the required sectional area of the rings will be

$$\frac{375 \times 7 \text{ (external radius of tank)}}{11{,}200} = \frac{2{,}625}{11{,}200} = \cdot 23 \text{ square inch.}$$

But, as a ring is provided at each of the 4 bottom joints of the brickwork, the cross section of each will be $\frac{\cdot 23}{4} = \cdot 06$ square inch and the diameter $\frac{5}{16}''$.

$\frac{3}{8}''$ bar was used for the tank shewn in the drawings.

For the depth from $4\frac{1}{2}'$ to $5\frac{1}{2}'$, the area of the 4 rings will be

$$\frac{5 \times 62\frac{1}{2} \times 7}{11{,}200} = \cdot 2 \text{ square inch,}$$

and of each ring $\frac{\cdot 2}{4} = \cdot 05$ square inch,
so that $\frac{1}{4}''$ diameter will suffice.

For the next foot ($3\frac{1}{2}'$ to $4\frac{1}{2}'$) the area becomes

$$\frac{4 \times 62\frac{1}{2} \times 7}{11{,}200} = \cdot 16 \text{ square inch.}$$

and for each ring $\frac{\cdot 16}{4} = \cdot 04$ square inch
so that $\frac{1}{4}''$ diameter is required.

Above this, old telegraph wire of about $\frac{3}{16}''$ diameter may be safely employed, and for the top 12″ or 18″ no reinforcement at all is really necessary for so small a tank.

II.—RACQUET COURT WALLS.

The plaster facing of racquet court walls is often the cause of trouble, and sometimes gives out a disagreeably hollow sound even in newly-constructed courts.

There are several causes likely to bring this about :—

(i.). The walls may have been covered with dust, or were too dry when the plaster was put on.

(ii.). The plaster may not have been properly wetted, especially near the tops of the walls.

(iii.). The brickwork joints may not have been raked out sufficiently to give a good key to the plaster.

(iv.). The mortar for the plaster may have contained too little cement for good adhesion ; or perhaps too much cement may have been used, so that cracks were produced (1 of cement to 1 of sand would probably do this).

Even with the best of supervision it is always possible that such mistakes may occur and ultimately cause the plaster to break away. In such a case, it is by no means easy to arrest disintegration when once it has commenced ; and new patches of plaster applied as a remedy, besides being unsightly, are nearly certain to crack in places.

By applying the principles of reinforced concrete a system has been devised which successfully overcomes these difficulties.

After the walls have been prepared for the plaster in the usual way, ordinary galvanized wire netting, preferably of small gauge, is suspended from nails (driven into the joints of the brickwork) in such a manner that it will lie from ¼″ to ½″ behind the face of the finished plaster ; this operation is easily carried out, especially if a little soft iron wire is used for securing the netting. When the netting has been properly fastened in position, the plaster is put on ; a proportion of 1 cement to 3 sand has given excellent results, though perhaps 1 to 2½ or even 1 to 2 might be better.

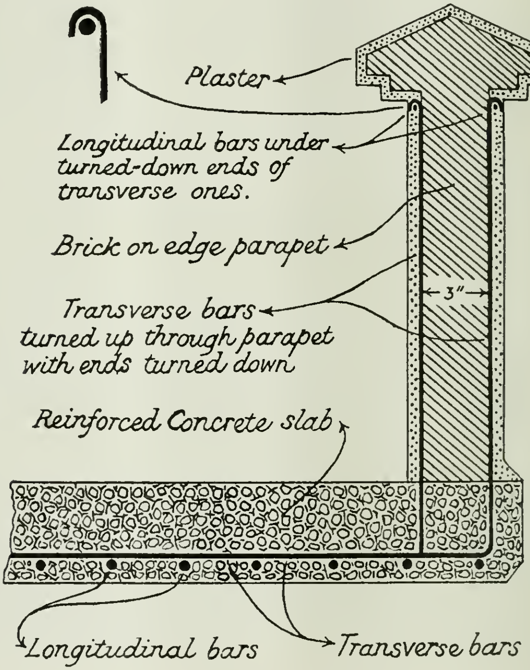
With this arrangement, if any cracks occur through bad workmanship, it will be found that the netting prevents the breaking away of patches of plaster, and the nails will compensate for any want of " key " in the brickwork, so that a good surface is always presented to the ball.

III.—REINFORCED BRICKWORK PARAPET WALLS.

Fig. 2, *Plate* III., shews a type of reinforced brickwork parapet wall made use of for several of the footbridges constructed at the Cordite Factory, Coonoor.

This also was designed as a substitute for reinforced concrete, which for such a structure would require complicated and expensive falsework.

The bridges themselves are simple reinforced concrete slabs, constructed on the Monier system, with longitudinal and transverse reinforcing bars ; but, during the construction of the slabs, extra long transverse rods were provided at intervals, and these were turned up vertically (as shown in the *Figure* below) to form the reinforcement for the parapet, which was built afterwards.


Plaster
Longitudinal bars under turned-down ends of transverse ones.
Brick on edge parapet
3″
Transverse bars turned up through parapet with ends turned down
Reinforced Concrete slab
Longitudinal bars
Transverse bars

(Not to scale)

Two such bars, one on each side of the wall, were given for every alternate bay of the parapet, and were tied to the longitudinal bars with soft wire. The brickwork was then put in hand, the bricks being laid on edge (in 1 to 3 cement mortar) in order to obtain a maximum width of footway ; the parapet was rather troublesome to build, and in most cases it would be simpler to lay the bricks on the flat.

On completion of the brickwork and coping, the whole was plastered over with about $\frac{3}{4}''$ cement mortar (1 to 3), and after this had set the wall was found to be very rigid.

With such a form of construction any degree of rigidity can be obtained by increasing the number of reinforcing bars ; and if these are suitably arranged, the parapet will practically become a kind of lattice girder which will materially strengthen and stiffen the whole bridge.

PLATE I.

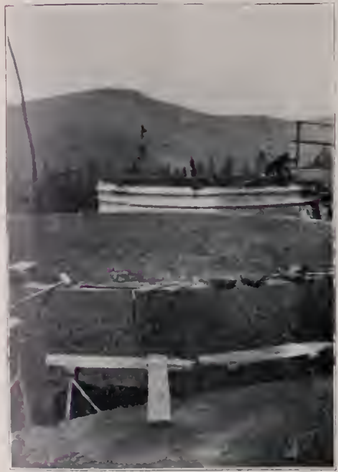


FIG. 1.—23 ft. diameter tank (25,000 gallons).
Showing radial wires.

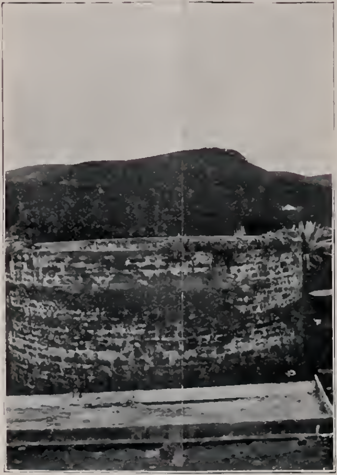


FIG. 2.—12½ ft. diameter tank (5,000 gallons).
Showing completed brickwork, with radials projecting.

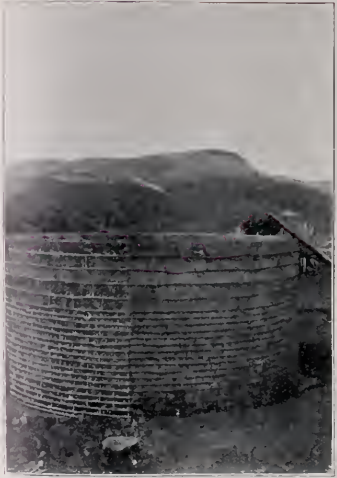


FIG. 1.—12½ ft. diameter tank.

Showing completed reinforcement partially covered with cement wash.

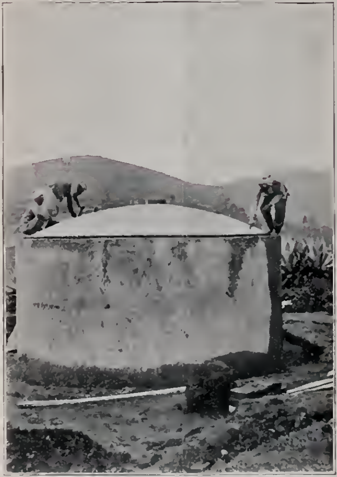


FIG. 2.—12½ ft. diameter tank.

Reinforcement plastered over, dome centering in position, and thrust rail on top of wall.

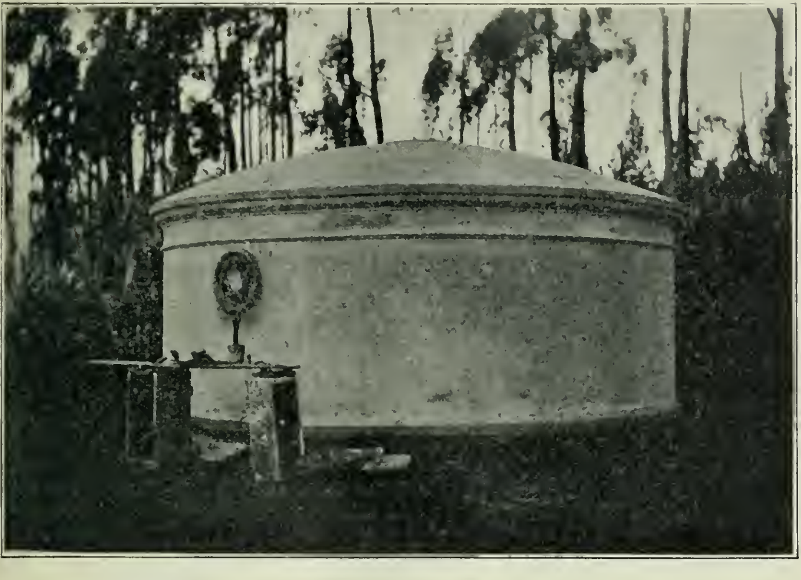


FIG. 1.—12½ ft. diameter tank, completed.

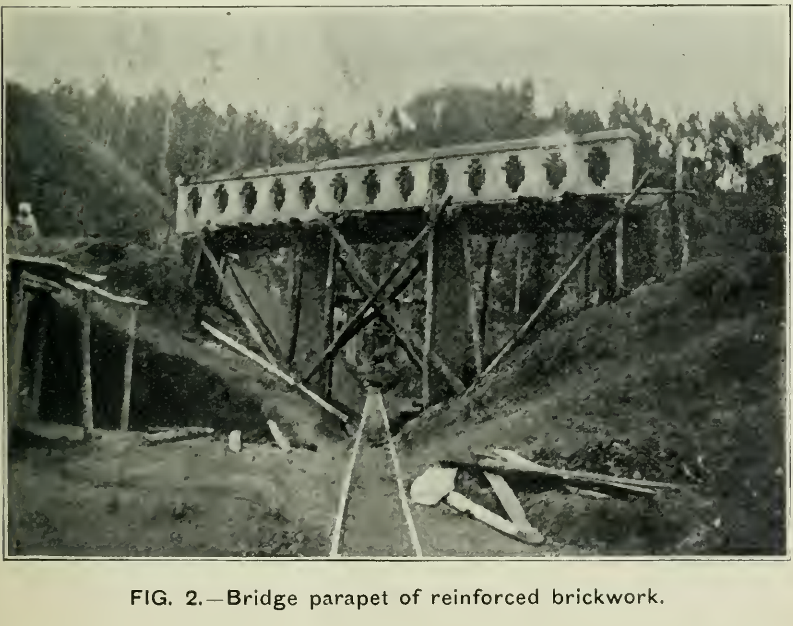
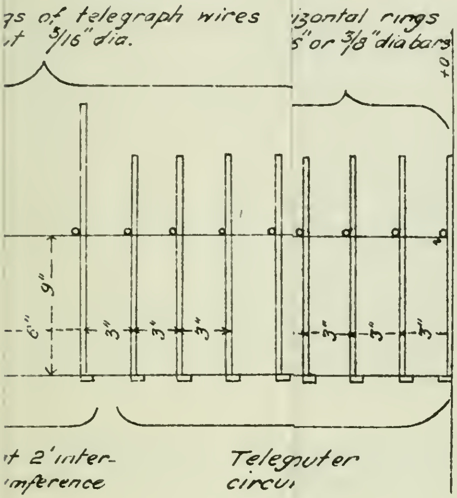


FIG. 2.—Bridge parapet of reinforced brickwork.

NFORCED BRIC

RRANGEMENT



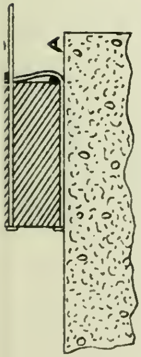
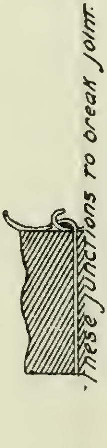


Fig. 4.



JOINTS AT ENDS OF RINGS

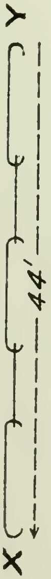


Fig. 6.

— HORIZONTAL RINGS MADE UP OF —
STRAIGHT LENGTHS HOOKED TOGETHER

—REINFORCED BRICKWORK WATER TANK.—

ARRANGEMENT OF REINFORCEMENT.

Fig. 2.

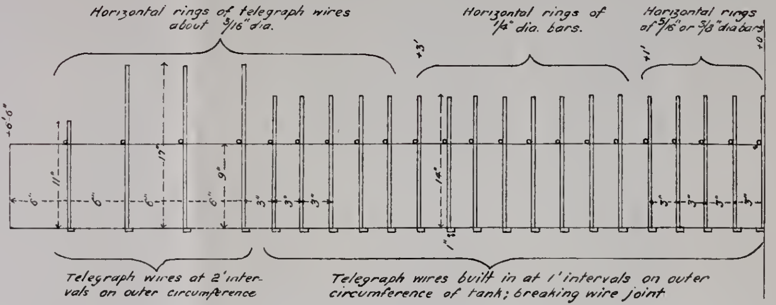

Horizontal rings of telegraph wires about 3/16" dia.
Horizontal rings of 1/4" dia. bars.
Horizontal rings of 5/16" or 3/8" dia bars
+0'-0"
+3'
+1'
+0
11"
17"
9"
14"
6"
6"
6"
6"
3"
3"
3"
3"
3"
3"
3"
1"
Telegraph wires at 2' intervals on outer circumference
Telegraph wires built in at 1' intervals on outer circumference of tank; breaking wire joint

Fig. 1.

— PART PLAN —

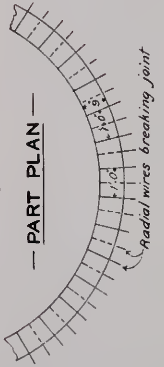


Fig. 3.

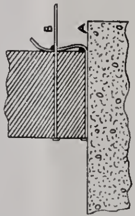
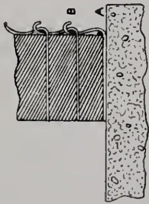
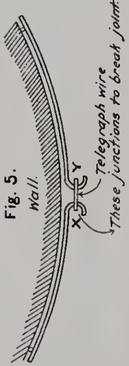


Fig. 4.



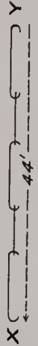
—CONNECTIONS OF RADIAL WIRES WITH EXTERNAL RINGS.—

Fig. 5.



JOINTS AT ENDS OF RINGS

Fig. 6.



—HORIZONTAL RINGS MADE UP OF STRAIGHT LENGTHS HOOKED TOGETHER

KWORK WATER TANK.—

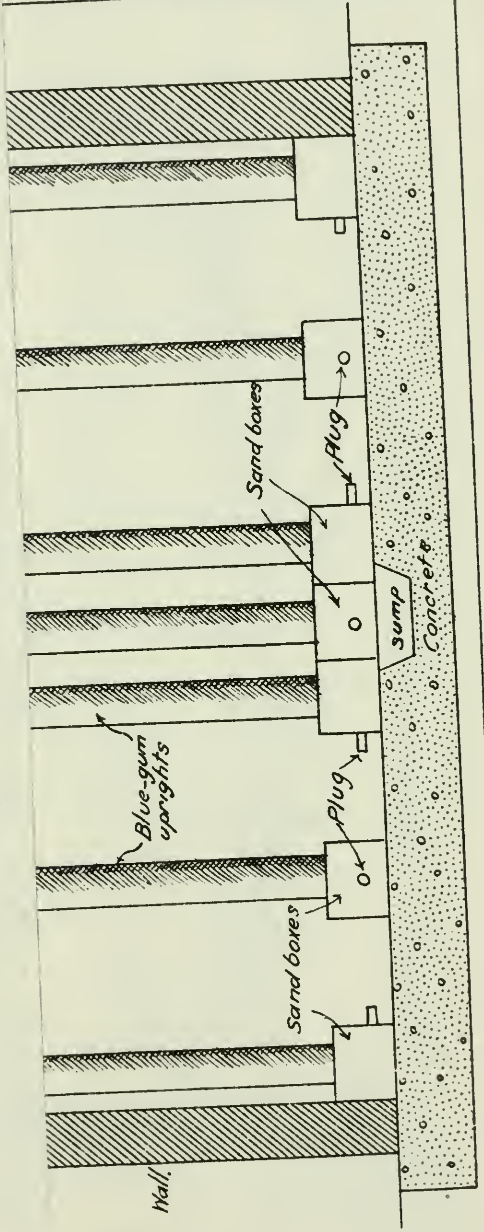
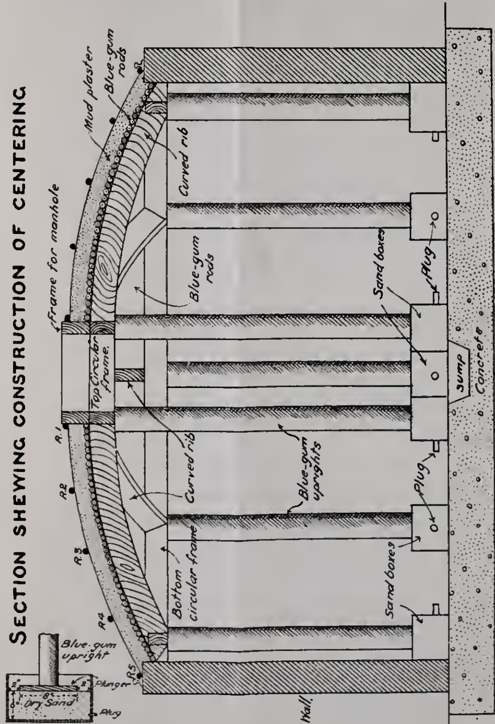


PLATE V.

—REINFORCED BRICKWORK WATER TANK.—



SECTION SHEWING CONSTRUCTION OF CENTERING

SECTION OF SAND BOX.

PLATE VI.

BRICKWORK WATER TANK—

MED

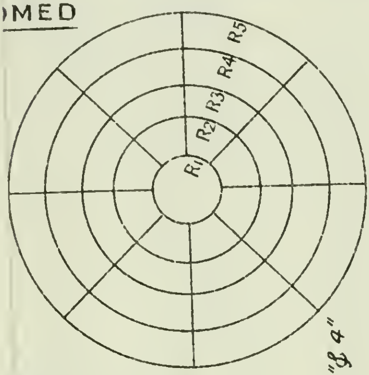


Fig. 1

—PLAN SHEWING RINGS— AND PRIMARY RADIALS.

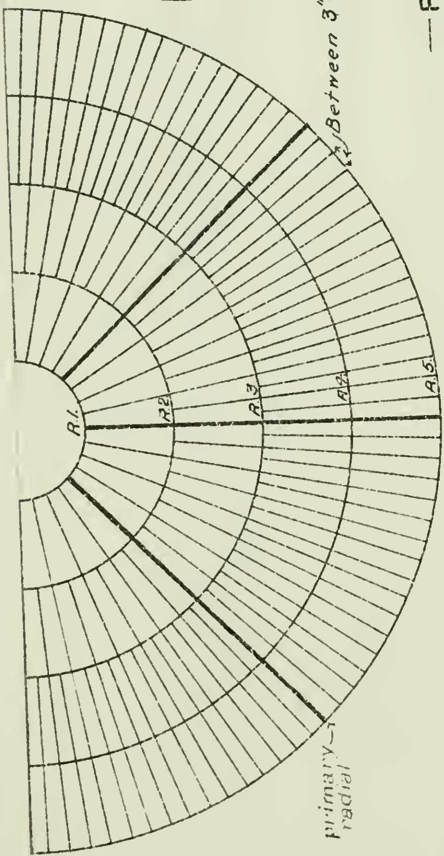


Fig. 2.

—HALF PLAN OF COMPLETED GRILL—

—REINFORCED BRICKWORK WATER TANK—

GRILL FOR DOMED ROOF

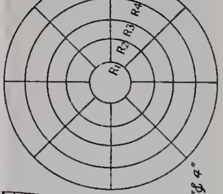


Fig. 1

—PLAN SHEWING RINGS AND PRIMARY RADIALS.

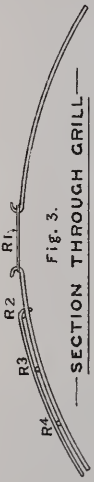


Fig. 3.

—SECTION THROUGH GRILL—

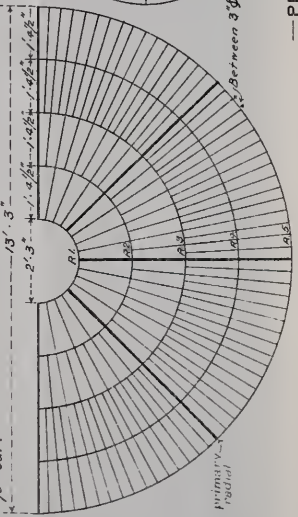


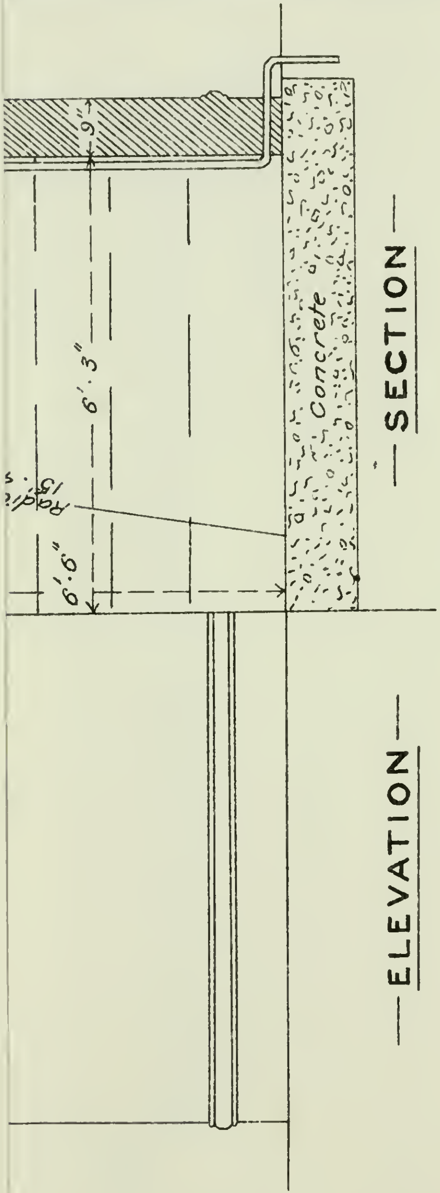
Fig. 2.

—HALF PLAN OF COMPLETED GRILL—

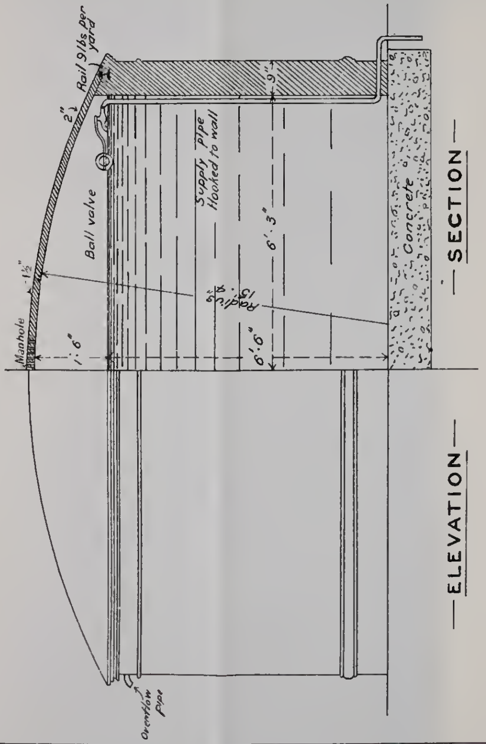
The whole of the grill (radials & rings) to be of telegraph wire except the manhole ring which will be a welded hoop of 3/8" bar.

PLATE VII.

CKWORK WATER TANK.-



—REINFORCED BRICKWORK WATER TANK.—



PAPER IX.

NOTES ON FIRE PROTECTION IN BARRACKS.

BY

Captain E. H. HARVEY, R.E.

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NOTES ON FIRE PROTECTION IN BARRACKS.

INTRODUCTION.

THE following Notes have been put together with a view to their being of some assistance in arranging for or improving the water supply of barracks and other War Department buildings.

They are mostly extracted from the very few books available on the subject, supplemented by the results of practical tests in barracks, and by information from current fire brigade technical magazines.

The first section deals with general principles of water supply and standard barrack apparatus. The second is a short summary of the use and capacity of present-day fire brigade apparatus,—intended as a guide in considering the nature of outside assistance likely to be available, and also as being, possibly, of some general interest.

PART I.

WATER SUPPLY, AND STANDARD APPLIANCES IN BARRACKS.

Water Supply Problem.

In arranging for the effective fire protection of a building it is necessary to consider the means of providing such protection at every part of the structure, including both the highest points and those most distant from the source of the water supply.

Practically speaking, this involves the provision of a supply of water at a sufficient pressure at the roof level of the building in as many jets as the water supply available will allow, regard being had to the extent and nature of the " risk " involved.

PRESSURE.

Pressure.

Firstly, as to pressure. Effective pressures for fire extinction vary from about 25 lbs. per square inch to a maximum of 100 to 120 lbs. The minimum useful pressure (*at the nozzle*) of any stream for fire-extinguishing purposes may be taken at about 25 lbs. per square inch, assuming that the nozzle is working at the *level of the fire* and that the latter is of no extraordinary extent ; with this pressure (25 lbs.) a stream can be thrown 32 feet high from a $\frac{13}{16}''$ nozzle with one length of hose.

With higher pressures the following results have been obtained for test purposes, working with one length of hose only and a $\frac{13}{16}''$ nozzle at ground level :—

(*a*). 25 lbs. pressure (head about 57 ft.), stream 30—35 feet high.

(*b*). 35 to 40 lbs. pressure (head 80—85 ft.), stream 45 to 50 feet high.

(*c*). 75 lbs. pressure (head about 170 ft.), stream 80 feet high.

The loss of pressure in a canvas hose is very considerable and a large allowance must be made for this :—4 to 8 lbs. per 50 ft. length, roughly speaking.

The above pressures may be taken as typical cases of what may be generally met with in barracks—

(*a*), being the lowest serviceable pressure, only really effective for the protection of one-storey buildings.

(*b*), a medium pressure, about equal to what may be obtained by the use of a manual fire engine.

(*c*), a high pressure, adequate for the protection of 4-storey buildings.

Manual Engines.

A good manual engine will give 35 to 45 lbs. pressure, so that where the normal hydrant pressure is less than this a manual should be utilized.

With the hose from a manual carried upstairs to the 2nd floor of a 3-storey building, a good stream can be thrown 40 or 50 feet from the nozzle horizontally, and this is adequate for the protection of the roof ; but on the top floor of a 4-storey building the delivery is not more than 20 or 30 feet, and more pressure becomes desirable.

If the engine is lifting from a sunken tank, the total power is diminished somewhat; in this case everything depends on the suction hose being in perfect order and connected up very tightly indeed (a result not always obtained with unskilled men).

With the $\frac{7}{8}''$ ($\frac{14}{16}''$) nozzle supplied by the Ordnance Store Department, a larger stream can be obtained for work under the above conditions ; and this is very effective for " inside work," *i.e.*, with the hose taken upstairs and within close range of the scene of the fire, as should always be done where possible.

Gravitation Pressure.

For effective protection in a building of more than 3 stories, as the maximum effective pressure of the manual is not more than 35 to 45 lbs. per square inch, it becomes necessary to resort either to high pressure on the mains by gravitation or to the use of a steam fire-engine. Having regard to the expense of keeping an engineer in readiness for the management of a steamer, the most economical method of protecting large barrack buildings is usually a high pressure water supply ; and a pressure of 60 to 70 lbs. per square inch, which is obtainable in many towns, will be found adequate for a building of 4 stories. With sound mains and valves of the best material this pressure can stand on the pipes safely under constant service, and provides the troops instantly with the means of throwing powerful jets to a height of 70 to 80 feet without engines ; this is sufficient for all ordinary purposes.

Dealing again with the practical results of the higher pressures of water, it may be noted that, with ordinary nozzles, the stream, after reaching a height of 50 or 60 feet, becomes more or less broken into spray by wind. But in actual practice the value of these high pressures is found in giving a margin for counteracting friction in hose.

Requirements for Buildings of Various Heights.

Comparing the results previously given with the average heights of buildings, it may be laid down that a 25 lbs. pressure with hydrants at close intervals may be taken as sufficient for the protection of one-storied buildings ; while for 2 and 3-storied buildings, 40 or 45 lbs. should be provided ; and for 4-storied buildings at least 55 or 60 lbs., preferably 70 or 80 lbs.

The pressure may be obtained either by gravitation or by use of engines.

From the foregoing remarks it will be seen that, where the hydrant pressure is *less* than 35 lbs. per square inch, the barrack manual engine will be *necessary* if the buildings are *more* than 1 or 2 stories high, and an *advantage* in any case. If the buildings are upwards of 3 stories high, a steam engine or high-pressure main should be available.

Generally speaking, however high the hydrant pressure, a fire-engine (even a manual) should always be kept in reserve in case of an accident to the main or temporary reduction of the pressure owing to repairs, etc.

In calculation of pressure by gravitation it may be assumed that every 33 feet in height of reservoir gives nearly 15 lbs. pressure of water, so that a reservoir at a height of 100 feet gives a pressure about equal to the power of good manual engines.

NUMBER OF JETS.

We next come to the question of amount of water and number of jets.

Discharge of ¾″ Jet.

Taking the general run of buildings, it will be desirable to allow at least two ¾″ jets for small detached blocks, such as huts; and at least four such jets for large blocks of barracks and for officers' and married quarters. Roughly speaking, a ¾″ jet at ordinary pressures may be taken to discharge from 60 to 150 gallons per minute, accordingly as it is worked from a manual, a steam engine, or a high-pressure hydrant.

Diameter of Main.

In calculating the number of ¾″ or ⅞″ jets supplied direct from the main, the general rule may be laid down that, as the diameter of the standard fire hose is 2½″, if a certain number of such jets be required to be worked from a given main, the sectional area of that main should be equal to the required number of jets multiplied by the sectional area of a 2½″ pipe.

To allow a margin for friction and deposit in mains, the 2½″ hose may be taken to practically exhaust a 3″ main. A 4″ main will therefore (as laid down in the *Barrack Synopsis*) work 2 hydrants *and no more*, unless with very exceptional pressures; and a 6″ main, which is the minimum laid down for fire protection in the *Synopsis*, will be needed to give 4 efficient jets.

Speaking generally, therefore, with a good pressure a 3″ main will only give one efficient hydrant jet or supply one manual engine, and is only suitable for a short branch to a single hydrant; a 4″ main will just work two jets; and a 6″ main is the minimum desirable for really good supply where there are *large* buildings. (By experiment, I have found a 3″ main give only one ¾″ jet at *35* lbs. pressure; on opening a second hydrant with one length of hose and ¾″ nozzle, the first jet,—40 or 50 feet high,—was reduced to about 15 feet high, the second being equally weak).

In practice, should a case arise where a fire has to be dealt with on two sides and a 3″ main only is available, the only possible course to adopt would be to divide the line of hose by a "breeching" (or "Y" piece) and use two ½″ or ⅝″ jets, that is if the "breeching" and suitable nozzles are available.

If a steam fire-engine is to be supplied (unless it be a very small one) 6″ is the least diameter desirable for the main. If 2 or 3 steamers are available, an 8″ or 10″ main will be none too large. (Numbers of steamers at London fires can only be worked on very large mains in principal thoroughfares).

In concluding the remarks on water-pressure and size of mains, it is most important to remember that a good pressure alone, without a sufficiently large main to enable it to be maintained when hydrants are at work, is practically useless. Therefore in examining the fire system of old buildings reliance must not be placed on tests by pressure-gauge alone. An ignorant plumber (if not supervised) may connect a 2½″ hydrant with the main by a 2″ or even smaller pipe; the pressure-gauge will, nevertheless, show the full pressure due to the available head of water until the hydrant is opened, when the throttling effect of the small connection will become apparent in the feebleness of the jet obtained.

In all cases it is most necessary to thoroughly investigate the size of the underground connections throughout the system.

Fire-Mains inside Buildings.

In connection with the provision of internal fire-mains and hydrants the following points should be considered:—

(*a*). A clearly-marked stop-valve should be fixed at the entry of the main to the building, but *well outside* the latter, so that it can always be got at safely and conveniently, even if a very serious fire occurs. In such an event it is possible that those who may at first attack the fire with the inside hydrants will be driven from the latter before they have time to properly shut them off; and unless the internal main can be shut off from a safe position out-of-doors, the pressure on outside hydrants will be spoilt and the subsequent operations of the fire-brigade hampered or rendered useless.

(*b*). Where the pressure on the internal fire-main is found to be low on the upper floors—as will be the case where the supply is drawn from tanks on the roof—pumping power should be provided on these higher levels. (An apparatus known as the "Pressure Augmenter" may be obtained, which consists of a hand-pumping machine permanently attached to the main).

W.D. Manual Engines.

Types of Engines.

"No. 1" Engines are worked by 22 or 24 men. "No. 2" size engines—a medium size for 16 men—are no longer built. "No. 3" engines are small machines with a small bore hose ($1\frac{1}{2}''$), such as are used by Railway Companies at Stations, etc.; being worked by 6 or 8 men they are useful in small detached barracks, where only a very few men are available and where hydrants are not effective.

Power of Engines.

The W.D. "No. 1" Manual Engine throws 100 gallons per minute (*nominally*) 90 ft. high; this is a maximum height under test conditions, working at a pressure higher than the 35 lbs. to 45 lbs. which may be expected to be maintained by unskilled men in continuous working.

All fire-engine tests, as in the case of other machines, show maximum possible results. 50 to 60 feet may be said to be the usual height reached by a manual jet, if the engine is in good order.

In all manual engine tests it is necessary to *fully* man the levers according to Regulations. This is sometimes not done, and those in charge of the engine complain that it is ineffective, whereas it is perhaps working with half the proper complement of men.

I have found that with an old engine a $\frac{5}{8}''$ nozzle will give good results; and, where there is outside property adjacent to high W.D. buildings, it is worth while to have the means of keeping the latter covered even by small jets in case of fire in the former.

Use of Various Jets.

Another point to be attended to is that the proper nozzles should be used on the branch pipes. The figures showing diameter of orifice will be seen cut in the gun-metal on the side, thus, $\frac{13}{16}$. The $\frac{13}{16}''$ are used for throwing jets to a height from ground level, as in protecting a high building from fire in an adjacent one; the $\frac{14}{16}''$ ($\frac{7}{8}''$) for "inside work" with the hose upstairs or in at a window; the fan-spreaders for small fires in rooms at the early stages, or for such cases as grass and rick fires, where a large spreading shower of water is more needed than a strong and concentrated jet.

Generally speaking, fire nozzles vary in size from $\frac{1}{2}''$ to $1\frac{1}{2}''$ for engines (including steamers) of ordinary capacity; the $\frac{3}{4}''$ or $\frac{13}{16}''$ being the most usual working size.

In cases where a fire occurs at a long distance from any available hydrant,—as in an isolated building, or one standing back a long way from the road where the main is,—the manual will often be useful to increase the effective pressure; and in such cases it will be found advantageous not to station the engine close to the hydrant, but to take it as far up the line of hose towards the site of the fire as the hydrant will deliver a sufficient supply of water into the cistern, the object being to shorten the distance between the engine and the nozzle and so get as good a jet as possible.

For very great and extensive bodies of fire, such as a storehouse or large building well alight, nothing but the largest nozzles under highest pressure available is of real use; small weak jets do not allow those using them to approach close enough to do any good. Therefore, where storehouses or other important risks have to be dealt with, all efforts should be made to secure a high hydrant pressure (60 to 70 lbs. on large mains),—hydrants at close intervals,—and the services of steam fire-engines. The *force* of water in each jet is generally of more importance than the quantity.

PART II.

OUTSIDE ASSISTANCE; FIRE BRIGADES AND SPECIAL APPARATUS.

MANNING OF FIRE BRIGADES.

Public Brigades.

Speaking generally, only cities and towns with a population of 50,000 to 100,000 and upwards find it worth while to maintain a considerable permanent staff of firemen and horses ready for instant turn-out. Smaller places, as a rule, have only one or two permanent men living in the station, with the remainder on electrical call, paid for by the attendance and by a "retaining fee"—or giving their services voluntarily.

Police Brigades.

Most of the larger towns employ part of their police force as permanent or auxiliary firemen, under police discipline; this arrangement is economical and avoids the expense of keeping up a separate civilian fire brigade.

Under the conditions of an Act of Parliament dated 1893 police may be permanently employed as firemen, but to obtain the Government grant in aid of their pay it is necessary that they should perform street duty as police; if they are merely sworn in as constables for purposes of discipline and pension and only act as such on emergency, they can, if entirely paid by the Local Authority, be employed solely as firemen. The officers and steam engineers of police brigades largely come under this latter class; the remainder of the police firemen are placed on "point" duty or very short beats in charge of light hand appliances, so that, while carrying out their obligations as to police duty, they are also on watch as firemen. It is customary to drill the remainder, or the majority of the remainder, of the police force sufficiently to act as auxiliary firemen who can augment the permanent staff as required.

"Retained" and Volunteer Brigades.

In the towns of lesser size, either voluntary firemen or "part paid" men (*i.e.*, those who are paid a fixed sum for each attendance whether at drills or fires) generally provide the *personnel* of the brigades. Where a police brigade does not exist and where a large reserve of men is occasionally required, the "part paid" men may be advantageously combined with a small permanent staff (example, Southampton).

Where, however, the town has a population much in excess of 100,000, the calls are likely to be so numerous that only a fully-manned professional brigade or police brigade is likely to effectually deal with them without entailing hardship on men who are only able to devote a part of their time to their fire brigade work.

Steam Fire Engines.

Pumping Power.

Steam engines are not often provided by the War Department, but the supply of water for them should be arranged for where they are available, as is now generally the case in England. The smaller sizes, used generally in small country towns and in the suburbs of large cities, pump 200 to 250 gallons per minute and work two or three effective jets. They are light, and therefore suitable to long runs in country districts.

For general town work in large places the more useful capacities are 350 to 500 gallons per minute, giving three or four jets.

Very large engines, pumping 600 to 1,000 gallons per minute (and even more) are used in some seaports, in manufacturing towns and in the Royal Dockyards; but these are less suitable for general work, as they are heavy for travelling long distances and may take two or three hydrants to supply them. They are well fitted for waterside work, where the sea or a river is close alongside the risks which they have to protect; and they are of very great power and effectiveness where, as in these cases, the water supply permits of their use conveniently.

Generally speaking, where a town has a high-pressure hydrant system, steamers are only needed for large fires; and a few *large* engines, turned out on the second call when specially asked for, are most useful. In places with a lower pressure, as in London, there is more use for small and medium steamers (260 to 450 gallons capacity) sent out at the first call, the hydrants being less equal to the general run of the work.

Pressures.

The pressure of water obtainable from steam fire-engines will reach to as much as 120 or 130 lbs. per square inch; 80—100 lbs. is a common working pressure. But they can of course be run at any lower pressure where the water supply is limited. They have the great advantage (in country districts especially) that they are capable of pumping through lines of hose of great length, and thus can protect property a long distance from the sources of water supply, which are so often limited to river valleys.

Boilers.

In choosing an engine of this, as of all other classes, it is of the utmost importance to have a large boiler. Boilers cut down to the minimum power for purposes of saving weight contain little water and raise steam very quickly, but are troublesome to manage when at work and unreliable except in the hands of very skilled men. It is more satisfactory in the long run to have a boiler slightly slower in raising steam, but capable of maintaining it easily and without undue forcing and attention when at work.

Eight to twelve minutes may be allowed for getting up steam from cold water,—more with inexperienced engineers and bad fuel. Less time is needed, *i.e.*, 2 to 4 minutes, if the boiler is kept hot over a gas burner (as in London and large towns).

Time required to "Turn-Out"

In a first-class fire station, with men close at hand on electric bell call and horses standing ready, a day turn-out may be taken at 30 seconds to 1 minute; at night 2 to 3 minutes, according to position of men's sleeping quarters and arrangement of station. In small towns, where horses are provided by contract when wanted, 5 to 10 minutes will be required, and often more.

Travelling Time.

With first-class horses kept specially for the work (as in London and large towns) fairly light machines, such as horsed escapes, manuals and small steamers, may be driven a mile in 4 minutes; in the case of small towns, where "chance" horses are supplied by contract, the speed may be only 7 or 8 miles an hour.

Motor Steamers.

Motor steam fire-engines, burning oil fuel, are now being constructed, and can turn out in 1 to 2 minutes if kept under low steam pressure. The same engine which propels the machine works the pumps,—the road-wheels being disconnected and the pumps thrown into gear by means of a clutch. They are best suited for places where a permanent staff of firemen are employed. Among English cities and towns now using them are London,* Tottenham, Brighton, Portsmouth, Plymouth, and Liverpool.

[* Note.—The two London engines are of special experimental types; the remainder alluded to,—besides several in use in smaller English towns and in Colonial stations,—are of Messrs. Merryweather's "Fire King" standard type. As an instance of the range of action of these engines, a case is lately reported from Brighton,—where the "Fire King" motor steamer ran to a

With reference to footnote on page 192. Since this was written, an engine of the "Fire King" pattern has been added to the strength of the London Brigade.

The use of petrol-motor apparatus is also being steadily developed, including petrol-driven escapes and hose-tenders, chemical engines, and machines combining the above with a powerful motor-driven pump, having the capacity of a small steamer and using the full-sized hose. (Example at Finchley, N. London).

In connection with this subject it may be mentioned that, within the last few years, the introduction of oil-fuel (*i.e.*, petroleum) has been successfully effected by leading fire-engine makers—both for horsed and motor steamers. For the latter it has the special advantage that a "working fire" can be instantly obtained, enabling the engine, as stated above, to turn out in the shortest possible time; and for all classes of steamers it has the same value. The minutes lost in obtaining a solid coal fire, and the emission of volumes of smoke and sparks are disadvantages avoided entirely by the use of the oil-burner. Owing to the fierce and rapid effects of its action it is desirable, however, where it is adopted, that the water in the boiler should invariably be kept hot; and, generally speaking, it appears to be peculiarly fitted for work in large cities, where the principal risks are often so close to the fire-stations (as in London) that coal-burning (horsed) engines may reach their work and be connected up before the boiler has gained enough steam to start pumping.

CHEMICAL APPARATUS.

Chemical apparatus is essentially employed for "first-aid," and for dealing with small fires where it is desirable to minimize the damage done by water; it enables a fire to be immediately attacked by the occupants of a building, or by the firemen on first arrival at the scene of work, without any delay being incurred by having to connect up with hydrants.

General Description.

The principle of this class of apparatus may be compared to the action of a soda-water machine. A closed cylindrical tank, full of water, is carried with a charge of soda and one of acid, which are instantly mixed when required by turning certain screws, etc., that break the capsule or bottle containing the acid and allow it to escape on the soda; a strong pressure of the resulting carbonic acid gas expels the water in the tank with great force through a small-sized hose and nozzle. Of hand apparatus one of the best kinds has a weight inside it; on the cylinder being turned upside down the weight breaks the bottle containing the acid.

Chemical apparatus may be roughly divided according to power into three classes:—

fire at Lewes (on the 4th October last), and was playing on the fire in 25 minutes from the time of leaving the Brighton fire-station,—a distance of eight miles. This is an engine of about 400 gallons (per minute) pumping capacity, in charge of "Police Fire Brigade."

Hand "Extincteurs"

(*a*). Hand "Extincteurs," carried by one man on his shoulders, containing 7 or 8 gallons. These are suitable for private use for holding a small fire in check till the arrival of assistance.

Small Chemical Engines.

(*b*). *Small* Chemical Engines, holding 35 or 40 gallons of water in a cylinder permanently attached to the carriage of a horsed escape or hose tender. These are intended for dealing with small fires; or for checking the spread of flame the instant the fire brigade arrive, while the hydrants and large hose are being got ready. Two men can work the chemical apparatus, which has its own length of 75 to 150 feet of small hose (similar to garden hose), coiled on a reel or in a cage, and can be played on the fire for 7 or 8 minutes without needing re-charging. This is a very useful method of extinguishing small fires with the minimum of water damage, especially in the case of private houses, shops, etc., where there are valuable goods, furniture, and so forth.

The chemical cylinder is fitted with a pressure gauge and an inlet, screwed to the ordinary hose gauge, so that it can be quickly refilled from a hydrant and set to work again with a new charge of acid and soda, spare charges being carried with the machine. It has also an arrangement of paddles, turned by a handle outside, to facilitate the mixing of the charge and rapid generation of gas.

Large Chemical Engines.

(*c*). Machines larger than those mentioned in (*b*). These have two cylinders, capable of being worked and charged alternatively so as to give a continuous jet,—each holding 60 or 70 gallons of water; they are combined with a hose tender and carriage for men, and are usually drawn by a pair of horses.

These machines, carrying hose and firemen, are perhaps less *generally* useful than class (*b*) which are small enough to be combined with a horsed escape. But they are of value in districts where hydrants are few and pressure bad, as is often the case in suburbs of towns. Carrying a supply of water with them, they are, *if able to reach their work quickly after an alarm*, of great use in such cases. As, however, their effectiveness largely depends on this quickness in getting to work, they may be considered as special appliances for the use of permanent brigades in protecting districts where there is bad water supply, rather than as part of the general equipment of the average brigade.

The sizes in classes (*b*) and (*c*) are also fitted on hand carriages for the protection of works, public institutions, etc., in addition to their adaptability for general fire brigade work. They of course require attention to keep them efficient.

AUTOMATIC SPRINKLERS.

For the automatic protection of stores and similar buildings the War Department have largely adopted the "Grinnell" type.

This sprinkler is set in action by the heat of fire in its vicinity melting a joint of fusible solder; this releases a hemispherical valve seated on a flexible diaphragm, and allows a strong stream of water to impinge upon a circular metal deflecting-plate, spreading a heavy shower in all directions. The combination of a fairly large stream with a deflector has the practical advantage, over distribution by means of perforated "roses" or pipes, that there are no small openings to become choked by dust and dirt.

The makers recommend that the sprinklers be attached at intervals of 8 to 10 feet to distribution pipes at about a similar distance apart at ceiling level. A constant pressure of at least 10 lbs.* per square inch should be provided at the level of the highest sprinkler; or if the supply is from tanks on the roof, the bottom of the tank should be at least 15 feet above this same level. With a pressure of only 5 lbs.* a floor area of 100 square feet may be covered. Tanks should hold at least 5,000 gallons where the number of sprinklers does not exceed 150, and particulars as to size can be obtained from the makers when a larger number have to be provided for; such tanks should always be covered.

Another very important feature of the system is an automatic arrangement which gives warning—by means of a gong outside the building—of any escape of water, whether due to leakage or to an actual outbreak of fire. These sprinklers, it may be mentioned, have been installed in the Central Clothing Depôt for the Ist Army Corps at Aldershot and in the new buildings of the Army and Navy Stores in London.

(In arranging for such an installation, reference should be made with regard to questions of water supply to Messrs. Mather & Platt, Ltd., the present makers).

[* NOTE.—These extremely low pressures may only be regarded as the absolute minimum requisite for working a "sprinkler" system; they are not adequate for throwing a useful jet from a standard fire-hose under the ordinary conditions when a fire has made some headway. As stated in the beginning of Part I. of these Notes, a minimum of about 25 lbs. per square inch is needed to give a good jet—even for work at short range; and, if at the highest part of a building the "head" on the mains will only give 5 lbs. or 10 lbs. pressure, either a portable or stationary fire-engine should be provided to give a better pressure and as an alternative means of protection to any "sprinkler" system.]

HAND PUMPS.

Hand pumps worked by one man are extremely useful in dealing with small fires. They are of similar power to the chemical "extincteurs" mentioned above, and either one or the other are carried by all up-to-date fire brigades on their engines and horsed escapes, a very large proportion of outbreaks being extinguished by these means alone.

Comparing a chemical "extincteur" with a hand pump, the former requires only one man to carry and work it, but is exhausted in a few minutes and needs to be periodically attended to and kept in order. The hand pump may be worked as long as the water supply holds out and needs little attention to keep it in order; but a "relief" will be necessary if it is to be continuously worked, and also two or three assistants to keep it supplied with water by means of buckets, etc.

Having regard to the above, it appears that the chemical "extincteur" is peculiarly suitable for the use of watchmen or private firemen in towns and places where plenty of other assistance may be expected in a few minutes.

But for an isolated building, such as a private residence in an outlying district, where it is certain that the fire brigade will take some time to arrive and where it is probable or possible that the supervision of the private fire apparatus may be somewhat overlooked, the hand pump appears to have its particular use. It can be worked by unskilled persons, by women or children, and is so simple that its use cannot fail to be understood, while it can be kept going as long as necessary. With two or three such pumps well directed a considerable fire could be dealt with.

HAND GRENADES.

Hand Grenades and such apparatus as Tube Extinguishers are solely for use as first-aid; and cannot take the place of efficient hydrants or pumping power in dealing with anything serious.

Wherever paraffin or spirit lamps are used, it is desirable to have buckets or boxes full of sand always handy to soak up burning oil in event of an accident.

FIRE ESCAPES.

For buildings of more than 2 stories fire escapes are desirable, and in the case of 4-storied buildings they are practically essential.

Vertical Running.

The old "vertical-running" escape is now becoming obsolete; it requires two or three trained men to run it with help, and is dangerous to move in high winds; to raise and lower it, as is so necessary in these days of overhead electric wires for tramways, etc., four trained men are needed.

Horizontal Running.

It has been superseded by the "horizontal-running" pattern, divided into the "curricle" class and the "sliding-carriage" type.

These classes differ in the method of attachment between the ladders and the carriage; but in both the ladders are easily raised by one or two men from the horizontal position in which they travel to the working one. The raising is usually effected by a small winch, winding in on a tackle which is so fitted as to "shorten in" the feet of the telescopic ladder towards the axle of the carriage.

In the "sliding carriage" the ladders, in altering their position from the horizontal to the vertical, run through a framework attached to the travelling wheels between rollers. In the "curricle" a simpler method of jointing between the ladders and the carriage is adopted.

Light escapes,—capable of being worked by one man,—are about 30 to 35 feet in height. The standard size is usually 45 to 50 feet which commands a 4-storied building.

Required Height.

In choosing an escape for particular buildings it is desirable to have a few feet to spare in height, so to give a handhold to men stepping off a parapet on to the ladder. For the new Winchester barracks a 60-foot "sliding carriage" escape was provided, the roof parapets being about 52 feet above ground.

Canvas Shoots.

Canvas shoots are not usually fitted now to modern escapes, as they increase the weight and have certain disadvantages. A box to contain a standpipe and a few lengths of hose is however often carried.

Necessity of Practising Men in Use of Escapes.

Where a fire-escape is provided for barrack use it is of the very utmost importance that a permanent party of properly trained men be established to work it, and that this party be constantly exercised—at least once a week. The escape should be inaccessible for the use of untrained helpers; because, if handled by persons unused to it, there is a probability of its causing a fatal accident. The permanent party should be practised in running the machine to every part of the barracks in turn, so that they may become thoroughly acquainted with any difficult positions. (In the

Winchester barracks such a party was formed from the Permanent Staff of the Militia and the Gymnastic Staff,—mostly married men living in barracks, and therefore generally available at all times).

Horsed Escapes.

For town work escapes are now usually horsed, being carried, lying horizontally with wheels at the rear, on a 2-horse hose tender. Eight firemen can as a rule be carried, 4 each side of the ladders, together with hose and standpipes for working from hydrants. Frequently a chemical engine is attached to the carriage as well.

Where there is a constant high water pressure, and the hydrants are numerous, such a machine will do all the average work in many towns without turning out an engine at all. The escape can be detached from the back of the hose tender in a few seconds, slipping off on to its own wheels in a vertical position ready for work. Escapes, carrying 2 or 3 men, are also built for draught by one horse.

Where there is a difficulty about obtaining horses and the hydrant pressure is low, the escape may be adapted to be carried on a horsed manual engine instead of on a hose tender, so that the *one* horsed machine may combine efficient life-saving apparatus with some amount of pumping power; but the apparatus is of course heavier and would chiefly be of use under the special conditions alluded to.

Private Fire Escapes.

Two of the chief varieties of these are the canvas shoot and the folding iron link ladders (attached to the floor and kept ready just inside the window).

It is very important that reliable persons should be in charge of the lower end of a shoot-escape when working; and some space outside a building is required in order to enable the escape to be held out at a proper angle.

With the iron link ladders (which are similar to those fitted to railway signal posts, but jointed at each rung and lighter), a rope attached to the lower end of the ladder and kept coiled beside it (with its upper end made fast) will be found a great addition; it enables the ladder to be checked while being run out, and prevents it going away with a rush and straining its fastenings.

It is hardly necessary to say that, where one of the foregoing arrangements is permanently fixed, a position should be chosen as clear as possible of lower windows from which a fire is likely to break out strongly in the earlier stages of an outbreak.

SCALING LADDERS.

Scaling Ladders.

Scaling ladders in 6′ 6″ lengths are useful in gardens and courts where a wheeled escape cannot enter; but they need very careful handling by trained men, and more than 4 or 5 lengths cannot be put together with safety. They are awkward at heights above the 2nd floor (*i.e.*, when more than about 4 lengths are needed); and, as only *two* lengths are carried on each engine (whether steamer or manual),—giving a working height of about 10 feet,—it may take some time before enough are collected (by the arrival of several engines) to reach any height worth speaking of. They can, however, be obtained in sets of 4 to 6, mounted on a light hand truck, for use in special districts; or a set of 4 can be fitted on the top of a hand hose-reel or hose-cart, forming a useful light appliance for branch fire-stations.

These ladders, on the whole, are only used for life saving where the wheeled escapes cannot be used, but they are generally serviceable in carrying hose over walls, etc.

Hook Ladders.

Hook Ladders,—also known as "Pompier" or (in London) "Emergency" Ladders, are a special appliance only suited to the use of well-trained firemen. They are now carried in London and by the chief provincial brigades, and are useful in working from the top of the ordinary escapes and ladders to heights that would otherwise be inaccessible.

Each ladder is of a length corresponding with one storey of a building, and is hooked over the sill of the window next above; a chain of ladders being built up by hooking on from window to window as the firemen ascend.

These ladders are used in conjunction with "life lines," by which the persons to be rescued are swung down,—not carried. They are of great value in all towns for rescues from the back windows of high houses, where wheeled escapes cannot be brought into use owing to yard walls, and where the heights are too great to enable the ordinary scaling ladders to be conveniently used. They can be very easily carried on the horsed or hand escapes or on manual engines.

SMOKE HELMETS.

Smoke helmets are now generally in use among first-class fire-brigades; they may be supplied either (like divers' helmets) through a small hose by an air-pump outside the building on fire, or they may carry their own supply of air compressed in a small reservoir and admitted to the helmet by an adjustable valve. In the former type the pumping is generally effected by means of a steamer running easily and acting as an air-pump.

Smoke helmets are particularly useful in confined situations, such as basements or between decks in ships.

HOSE AND HOSE FITTINGS.

Hose Reels.

Hose reels have the advantage of enabling a long line of hose to be laid down quickly by persons who may not have much practice in fire drill, or where (as in a small detachment barrack) only two or three men are perhaps immediately available for quickly connecting together screw couplings. It is very necessary, however, in using reels to see that the hose is well dried before being coiled up on them, as otherwise the inner coils will deteriorate.

Where a district is extensive, with good hydrant pressure, hose reels may be built for horse draught, one horse conveying the reel and two or three men as a "first turn-out machine."

Hose.

Canvas hose is generally replacing leather on account of its lightness and cleanliness; but it has not the durability of leather and is particularly liable to be spoilt by dragging over the gravel of barrack parades. For public work, however, it has the advantages of lightness and compactness, a 100-foot length of canvas hose, coiled up, being as little cumbrous and about as compact as a 40-foot length of leather; this is an important consideration in stowing a quantity of hose in the locker of an engine.

Thorough drying after use, preferably hung up, is most important to the preservation of canvas hose; if this point is not attended to the hose will always be unreliable and will probably burst as soon as connected up for work, causing delay and perhaps water damage.

Leather hose is usually made in 40-foot lengths; canvas in 50 and 100-foot lengths.

Couplings.

Screw couplings are used by the London and many other important brigades as being always reliable; but spring and instantaneous couplings find favour in some places, and in drill competition work. "Connectors," with one end screwed and the other "instantaneous," can be bought from engine makers; and are small and compact fittings, enabling brigades who use the two different classes of couplings to work together.

The foregoing notes give only a very short summary of the question of fire protection, and the following books may be specially recommended to those who may have occasion to go into the subject more fully.

Books of Reference.

Fire Protection of Mansions, by James Compton Merryweather, Esq.
The Fire Brigade Handbook, by ditto.

For general information on the whole matter—including *personnel*, appliances, etc.—an interesting publication is the

Report from the Select Committee on Fire Brigades (Minutes of Evidence), 1899,

published by order of the House of Commons by Messrs. Eyre & Spottiswoode.

PAPER X.

METALLOGRAPHY.

BY

CAPTAIN R. K. BAGNALL-WILD, R.E.

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METALLOGRAPHY.

INTRODUCTION.

In a pamphlet of this size it is impossible to more than briefly touch upon the main branches of the subject; but it is hoped that these notes may be of assistance to those who are about to take up metallography, and it is thought that they may also render the perusal of the standard works more easy.

Much of the practical information contained in Part II. has been derived from experience gained by working under Mr. Stead's direction and from observation of the methods employed by Mr. Deby, of Messrs. Cammell's Works, Sheffield; by Messrs. Nash, at the Public Testing Works, Sheffield; and by Messrs. Taylor, Steel Works, Leeds.

The microscopical examination of metals is now generally known under the designation Metallography.

The study of the Microstructure of steel, iron and alloys generally has only received serious consideration during the last 10 or 12 years; and its practical application in the production and treatment of such materials for industrial purposes, although at present making rapid progress, is practically in its infancy.

The Microscopical examination of a metal or alloy not only aids in the detection of mechanical defects, often otherwise undiscoverable, but throws invaluable light on the effects of varying heat treatment.

As an example of its value the following case is of interest:—

" A rail failed on the Great Eastern Railway, causing a serious accident. The rail was nearly a new one from a batch represented by test pieces that satisfied the conditions of the specification. On examining a portion of the defective rail under the microscope the structure was found to be abnormal and such that weakness might be expected under certain conditions, namely those of continued alternations of stress; also from the nature of this structure the particular treatment this rail must have been subjected to during manufacture was apparent."

Test pieces cut from this defective rail, when placed in a testing machine adapted for continually reversing a given stress on the test piece, broke at 208,220 reversals, as compared with a test piece from a sound rail which withstood 14,460,000 reversals before failing; the stress applied in both cases being 19 tons per sq. inch.

DEFINITIONS AND GENERAL CONSIDERATIONS.

It is proposed to confine this paper to a few general considerations, and to deal mainly with the microstructure of iron and steel together with details of the apparatus necessary for its investigation and the difficulties that may be expected to be encountered in its use.

In order to more readily grasp the results obtained under the microscope in the study of steel, a few definitions are worthy of consideration; they are briefly as follows:—

Many changes take place in the molecular construction of steel in cooling from a high temperature to a low one; it is therefore necessary to carefully consider the possible construction and composition of similar solids.

Solid Solution.

A solid solution is a solid the components of which are two or more solids completely merged the one with the other and with an absence of any fixed ratio between the components.

A solid solution differs from a chemical compound in three chief features, viz.:—

(*a*). The components of a chemical compound, although completely merged the one with the other, form a new substance and lose their identity.

(*b*). A mathematical fixed ratio between the two or more components must exist for the formation of a chemical compound.

(*c*). The chemical forces which hold the dissolved bodies together in a solid solution are very feeble.

Osmotic Pressure.

If a concentrated aqueous solution be carefully covered with a layer of water, the dissolved substance will rise against the action of gravity until it is equally distributed throughout the entire mass of water.

The pressure the dissolved substance is thus capable of exerting against gravity is termed its *osmotic pressure.*

The same pressure is exerted in solids, but to a less extent.

The *eutectic* is an alloy of lower melting point than any other alloy of the same constituents in other proportions. *Eutectic.*

The composition and freezing point of a *eutectic* are constant, no matter what the initial ratio between the constituents of the alloy.

For example the *eutectic* of the Copper-Silver alloys has a composition Ag 72 per cent. Cu 28 per cent., and solidifies at 775° C.

The fusing point of copper is 1,090° C. and of silver 960° C.

Any alloy of copper and silver, other than the *eutectic* composition, solidifies above 775° C.; but solidification is not complete until a temperature of 775° C. is reached, at which point the liquid remain (which will be of the *eutectic* composition) will solidify.

If an alloy of, say, 30 per cent. silver and 70 per cent. copper be melted and allowed to solidify, then at a temperature of 950° C. copper will commence to fall out of solution, leaving a portion of the alloy still in the liquid state; and solidification will not be complete until a temperature of 775° C. is reached, when the *eutectic* (which will then be of the composition Ag 72 per cent., Cu 28 per cent.) will become solid, the excess copper having solidified previously.

In the previous example of an Ag—Cu alloy, the liquid remaining and surrounding the solid copper which will have commenced to solidify at 950° C. is termed the *Mother liquid.* Mother Liquid.

The definition of an *eutectic* presupposes its formation as a solid on the solidification of a liquid or molten mass; but in the case of steel, amongst many other alloys, there is a molecular reconstruction that takes place on cooling through a certain temperature range at which there is a separation of the constituents in the solid similar to the formation of an *eutectic;* indeed this term is frequently used to designate Pearlite, which is the constituent of steel referred to. The true *eutectic* of the iron carbon series, *i.e.*, the alloy of these two constituents that has the lowest melting point, contains 4·3 per cent. carbon, but Pearlite contains only ·9 per cent. carbon and is not formed until the solid steel has cooled to just below 700° C.; steel of this composition has a melting point about 370° C. higher than the true *eutectic.* Secondary *Eutectic.*

This Pearlite has all the properties of a true *eutectic* with this one exception, viz.:—that it is formed on the cooling of a solid solution instead of from a liquid or molten mass.

Such may be termed a *secondary eutectic.*

Howe designates a ·9 per cent. carbon steel as æolic, that containing less than ·9 per cent. carbon as hypo-æolic, and all above this hyper-æolic; but the term *secondary eutectic* is considered simpler and more expressive.

Selective Freezing.

Selective freezing may perhaps best be illustrated by an example. Take the case of an alloy of 60 per cent. gold and 40 per cent. silver. Here silver has a lower melting point than any of its alloys with gold, so that the *eutectic* consists of 100 per cent. silver, 0 per cent. gold.

On solidification the first layers freezing out are presumably those richer in gold than is the mother liquid.

If this is not so, then suppose that the first molecules to freeze out consist of 60 per cent. gold and 40 per cent. silver; this silver would tend to re-dissolve in the mother liquid, because the alloy created by its re-entry would contain more than 40 per cent. silver, and consequently be more fusible and remain molten at the existing temperature. This shows that unselective freezing is unnatural.

Again referring to this example, it is evident that, if this selection be rigid, then on freezing the whole of the silver will re-melt and enter the mother liquid until, on nearing complete solidification, the mass will consist of solid pure gold and liquid pure silver. That this is not the case is evident, for the first grains solidifying out contain both gold and silver; the silver is trying to re-melt, but is partially restrained by the slight affinity the gold exerts upon it in solid solution; hence each successive grain as it solidifies will be progressively richer in silver.

Selective freezing is therefore not rigid.

Nature of the *Eutectic*.

A *eutectic* may be either a solid solution or may consist of interstratified plates of its constituents.

The reason for this is as follows:—If the components of the *eutectic* are mutually soluble, the one in the other, the *eutectic* will be a homogeneous solid solution; but if the components be only soluble, the one in the other, in the molten state, then on freezing and consequent formation of the *eutectic* its components will reject each other, not being soluble in the solid state. The structure of the *eutectic* thus formed must therefore consist of alternate masses of each of the components.

Diffusion.

Diffusion in solids has been thoroughly investigated. There is in solutions a tendency for the dissolved particles to pass from positions of greater concentration to those of lesser concentration, the motive power being osmotic pressure.

The same thing occurs in solids, but the rate of diffusion is much slower owing to the higher intermolecular friction.

Segregation. In dealing with large masses segregation plays a very important part.

In the case of a large ingot of steel the top portion of the centre of the ingot will be richer in carbon than the rest of the ingot, because the higher the carbon content up to the *eutectic* ratio the lower the melting point; and it is evident that this is the last portion of the ingot to solidify, for the bottom of the ingot, being in contact with the cold cast-iron mould, will solidify before the head, which is only in contact with the air. Segregates are generally found near the centres of castings, and are most pronounced in very large masses.

Saturation. Two substances may be wholly mutually soluble, the one in the other. But if this is not the case, it is evident that there is a point at which one substance cannot take up any more of the other in solution; and then, if a further quantity of this second substance be added to the mixture, it cannot be dissolved, and therefore the mass will consist of a saturated solution of the second in the first and a proportion of the second substance in the free state.

This applies both to liquid and to solid solutions.

Structure. The various points now briefly touched upon must evidently influence the structure of the solid. There is also another important point, viz., time; for molecular movement in a liquid is slower than in a gas, and in the case of a solid it is very slow indeed.

The following examples are put forward as indicating various types of structure produced on freezing under various conditions:—

Take the case of a simple constituent in the molten state. On lowering the temperature until the freezing point is reached, solidification commences under normal conditions at various points throughout the mass, round each of the solid grains thus formed further grains solidify, each little mass growing and growing until it meets a contiguous mass and until finally the whole becomes solid. If the constituent be crystaline, the solid thus formed will consist of crystals formed of these little grains, possibly crystaline themselves. The boundaries of these crystals will be irregular, and the grains in each crystal possibly differently orientated from those in contiguous crystals.

Now suppose this simple constituent contains a certain quantity of a foreign matter of a lower melting point, which is insoluble in the constituent or is not isomorphous with it. Such foreign matter will be pushed forward by each group of grains as they are formed, and will eventually on complete solidification be found at the boundaries of each crystal, separating crystal from crystal.

In a structure of this nature it is evident that in the first case the strength of the material will depend on the cohesion between each group or crystal, as greater cohesion will probably exist between the grains forming the crystals than between the crystals themselves. The interlocking of such crystals may greatly add to the strength of the material should the cohesion between the crystals be slight.

In the second case the strength of the material must depend to a great extent on the strength of the foreign body separating the crystals and on the interlocking of the crystals themselves.

From these considerations it is easy to conceive what happens when an alloy of two constituents freezes. The excess metal, *i.e.*, that in excess of the *eutectic* proportion and consequently that having a higher melting point, will commence to freeze out and will continue to do so until the mother liquid has attained the *eutectic* proportions, each progressive layer of the excess metal becoming richer in the other constituent. The structure thus formed will probably be of one of two types, viz. :—

(1). The fir tree type, in which the excess metal will commence solidifying round various starting points throughout the mass, and will grow in spines in three directions, pushing the mother liquid before it, until the excess metal has all solidified, when the mother liquid (which will then be of the *eutectic* proportions) will solidify in the spaces between the spines. The structure of the *eutectic* will be homogeneous or interstratified accordingly as its constituents are mutually soluble or not in the solid.

(2). The landlocked type. If the freezing out of the excess constituent be conceived to occur in parallel layers in three directions, the *eutectic* will be isolated in cubes between each series of layers. The resulting structure will then consist of unsaturated layers of the excess constituent, saturated layers and the *eutectic*.

There are of course many variations of the above two main types of freezing.

Time as Influencing Structure.

The rate of freezing and of subsequent cooling has a very great influence on the structure of an alloy.

Sudden freezing may give rise to supersaturation; that is to say, an alloy may thus be a solid solution consisting of a supersaturated solution of one constituent in the other, instead of the normal eutectiferous alloy.

Sudden freezing, rate of cooling, etc., influence largely the amount of segregation and diffusion.

Temperature.

A point that should not be overlooked in considering the structure of an alloy is that the saturation point falls with decrease of temperature.

Cooling Curves.

It is impossible in general notes of this description to do more than touch very briefly on such a large subject as Cooling Curves.

The " cooling curve " may be best illustrated by the example given by most authors on this subject.

Illustrations of cooling curves obtained in cooling water, and in solutions of various percentages of salt in water, are given on *Plate* I., which shows also a " freezing point curve," obtained from a series of such cooling curves.

With reference to this *Plate* it is seen that the fall in temperature becomes slower and slower as the freezing point is approached. When this point is reached the temperature remains constant for a considerable period, and it is not until the whole of the water has become solid ice that the temperature will again commence to fall. These curves are obtained by immersing a flask containing the liquid, the cooling curve of which it is desired to determine, in a freezing mixture, and by means of a thermometer to follow the fall in temperature of the liquid per second; temperature and time form the ordinates and abscissa respectively of the curve required.

The heat generated in the passage of the water from the liquid to the solid state causes the arrest in the fall of temperature.

In a like manner every change, whether chemical or physical, occurring in a cooling mass is accompanied by thermal action and consequently will record itself on the cooling curve. The importance of this fact cannot be over-rated.

Plate II. gives a diagram embodying cooling curves obtained from the iron carbon alloys. It is the Roberts Austen diagram with certain of Roozeboom's modifications; and has been lately confirmed within narrow limits by Carpenter & Keeling, of the National Physical Laboratory.

This diagram should be constantly referred to when considering the constituents of the iron carbon alloys given in Part II. of these notes.

IRON CARBON ALLOYS.

Classification according to Carbon Content.

The following is a general classification of iron and steel according to the carbon content.

	Carbon Content.
Wrought Iron Mild Steel	0 to 0·3 per cent.
Steel	0·3 to 2·0 per cent.
Cast Iron	2·0 per cent. and over.

Allotropic Modifications of Iron.

Carbon is the most important constituent influencing the properties of iron. The conditions under which it exists, when present in varying percentages, and when subjected to varying heat treatments, will first be considered; the influence of the presence of other elements will be dealt with later.

Next to carbon the most important constituent of the iron carbon alloys is iron itself.

On allowing pure iron to cool slowly from its fusing point there are two points of recalescence in addition to the fusing point. These critical points occur at 895° C. and 765° C., and are called respectively Ar_3 and Ar_2.

It follows that iron must undergo molecular reconstruction at these points, and as the metal is pure these changes must be allotropic.

Osmond designates these various modifications by the following symbols:—

α iron is the modification existing after slow cooling below Ar_2.

β iron that existing under similar conditions between Ar_2 and Ar_3.

γ iron that appearing above Ar_3.

There is also a possible δ modification, existing above Ar_3 in very low carbon irons, but its identity is not thoroughly established.

The properties of these three forms (the δ form may be neglected) are as follows:—

α iron; magnetic; cementite is insoluble in it.

β iron; non-magnetic; dissolves neither carbon nor cementite.

γ iron; non-magnetic; dissolves both carbon and the iron carbide Fe_3C.

CONSTITUENTS OF IRON AND STEEL.

The following substances are revealed under the microscope in the iron carbon series when the alloy has been subjected to varying heat treatment.

Ferrite is pure iron, or rather practically so, as iron is not obtainable under ordinary conditions in the pure state. Ferrite.

Ferrite is soft and ductile, and is magnetic. Grains of ferrite are cubical crystals formed round the various centres of crystallisation.

Wrought iron consists nearly entirely of ferrite, but it is as a rule drawn out into fibres by rolling, the fibres being separated by thin layers of slag. These fibres of ferrite consist of an aggregation of grain crystals, and are therefore fibres in general appearance only.

Ferrite is an important constituent of steel that has been slowly cooled. It occurs in masses in the hypo-æolic steels.

Cementite is a definite carbide of iron Fe_3 C., *i.e.*, containing 6·67 per cent. of carbon. It is very brittle, harder than hardened steel, scratching glass. Cementite.

It occurs in slowly cooled steels and as massive cementite in hyper-æolic steels and cast iron.

Pearlite is the name given to the secondary *eutectic* of the iron carbon series, and contains ·9 per cent. carbon. Pearlite.

Slowly cooled steels consist of pearlite, and the excess substance: pearlite itself consists of interstratified plates of ferrite and cementite, and as its carbon content is ·9 per cent., the proportion by weight must be in the ratio of about 6 parts of ferrite to one of cementite.

The exact composition of pearlite is not quite definite.

In slowly cooled steels, between ·85 per cent. to ·95 per cent. carbon, the whole mass may consist of pearlite.

Steels containing less than ·9 per cent. carbon consist of pearlite and the excess substance ferrite, and those containing more than this proportion of carbon consist of pearlite and the excess substance cementite.

By reference to the diagram on *Plate* II. it will be noted that pearlite, ferrite and cementite separate out from the solid at a temperature far below the melting point.

Pearlite is a very striking example of a secondary *eutectic* in which the components are mutually insoluble, the one in the other, at and below the temperature at which its formation takes place.

Martensite.

Martensite exists only in hardened steel; its carbon content varies from ·12 per cent. to ·89 per cent.

It is obtained by quenching steel from a temperature above that at which the change into pearlite commences.

The state in which the carbon exists in martensite is the subject of considerable controversy. According to the "carbon theory" martensite consists of a solid solution of hardening carbon in iron, *i.e.*, the carbon is not definitely combined but exists merged with the iron, and is capable of causing hardening on quenching According to the "allotropic theory" martensite consists of a solid solution of carbide of iron Fe_3 C. in the γ allotropic modification of iron. According to Professor Arnold's theory martensite consists of a definite sub-carbide of iron Fe_{24} C.

Hardenite.

Martensite saturated with carbon, *i.e.*, containing ·89 per cent., is frequently called hardenite.

Austenite.

Austenite is probably a solution of carbon in iron.

It can be obtained on quenching a steel rich in carbon from a very high temperature by immersion in a freezing mixture.

Troostite.

Troostite is a transition form between martensite on the one hand and ferrite and cementite on the other.

Its composition is a matter of doubt, but it has usually been regarded as being martensite in the state of change into pearlite and therefore containing carbon.

A very interesting theory has been put forward by Boynton Harvard University, viz., that troostite is the β allotropic modification of iron.

His argument in support of this statement is as follows:—

Steel containing say ·45 per cent. carbon at a high temperature consists entirely of martensite; on cooling ferrite is rejected, and the carbon content of the martensite gradually increased until the saturation point (viz.:—·89 per cent. of carbon) is reached.

If a bar of such steel be heated to say 1,000° C. at one end, the other end being kept cool, and the whole then quenched, on examination the hot end will be found to consist of martensite only; then as the cool end is approached a new constituent appears, viz., troostite. As previously stated the martensite on cooling rejects ferrite and itself becomes richer in carbon; then where is this ferrite? It must surely be represented by the troostite.

If this bar be further examined towards the cool end, it will be found to consist of martensite areas bounded by troostite; and these martensite troostite grain masses will be found to be separated by ferrite.

If troostite be a transition form between martensite and pearlite, then it must contain nearly ·8 per cent. carbon, and therefore the martensite must be very poor in carbon; but this cannot be so as the martensite in this case has experimentally been found to be harder than the martensite found at the hot end of the bar.

This explanation carries great weight, but the considerations are not conclusive.

Troostite is found in steels containing from ·2 to 1·6 per cent. of carbon that have been quenched during recalescence. According to Boynton this constituent is sorbite in the case of steels containing more than ·8 per cent. carbon, for if troostite be β iron free from carbon it cannot exist in hyper-*eutectoid* steels. It seems more probable that the troostite in the hypo and hyper-*eutectoid* steels is β iron containing carbon, as in both cases it presents the same micrographical characteristics.

Sorbite.

Sorbite is a transition form between martensite and pearlite.

Martensite and sorbite can occur together, as can sorbite and pearlite; sorbite and pearlite frequently merge the one into the other.

Graphite.

Graphite is a characteristic component of grey cast iron. It is practically pure carbon.

When formed during the solidification of the metal it occurs in thin plates generally curved.

It is also formed under other conditions after solidification, when it occurs as a very fine and evenly distributed powder.

THEORETICAL MICROSTRUCTURAL COMPOSITION OF THE IRON CARBON ALLOYS.

Hall gives the two following tables showing the percentages of the various constituents theoretically present in the iron carbon alloys with varying carbon content; they should be carefully studied in conjunction with the diagrams on *Plates* II. and III.

UNHARDENED CARBON STEELS.

Carbon. Per Cent.	Pearlite. Per Cent.	Ferrite. Per Cent.	Cementite. Per Cent.	Carbon. Per Cent.	Pearlite. Per Cent.	Ferrite. Per Cent.	Cementite. Per Cent.
—	—	100	—	1·30	91	—	9
0·10	12	88	—	1·40	90	—	10
0·20	25	75	—	1·50	88	—	12
0·30	37	63	—	1·60	86	—	14
0·40	50	50	—	1·70	85	—	15
0·50	62	38	—	1·80	83	—	17
0·60	75	25	—	1·90	81	—	19
0·70	87	13	—	2·00	80	—	20
0·80*	100	—	—	2·10	78	—	22
0·90	98	—	2	2·20	76	—	24
1·00	97	—	3	2·30	74	—	26
1·10	95	—	5	2·40	73	—	27
1·20	93	—	7	2·50	71	—	29

* ·9 per cent. carbon gives 100 per cent. pearlite according to the latest researches.

QUENCHED STEELS.

			Percentage of Carbon.					
			·09	·21	·35	·80	1·20	2·50
Percentage, in volume, of martensite, ferrite, cementite, and pearlite.	Quenched above Ar_3.	M	77	—	—	—	—	—
		F	23	—	—	—	—	—
		C	—	—	—	—	—	—
	Quenched above Ar_2.	M	—	100	100	—	—	—
		F	—	—	—	—	—	—
		C	—	—	—	—	—	—
	Quenched between Ar_3 and Ar_2.	M	27	—	—	—	—	—
		F	73	—	—	—	—	—
		C	—	—	—	—	—	—
	Quenched above Ar_1.	M	—	—	—	100	94	80
		F	—	—	—	—	—	—
		C	—	—	—	—	6	20
	Quenched between Ar_2 and Ar_1.	M	11	31	56	—	—	—
		F	89	69	44	—	—	—
		C	—	—	—	—	—	—
	Quenched below Ar_1 or slowly cooled.	P	10	23	50	100	92	77
		F	90	77	50	—	—	—
		C	—	—	—	—	8	23

M = martensite. F = ferrite. C = cementite. P = pearlite.

Cooling Curve Fe and C.

The transitions and transformations indicated in the diagram on *Plate* II. have already been described in the case of steel containing less than 1·5 per cent. carbon.

The meaning, and indeed the position, of the lines to the right of this point are by no means well established.

The solid solution of cementite (Fe_3 C.) in iron, *i.e.*, martensite, becomes saturated when the carbon content reaches 0·89 per cent.

Austenite, or the solid solution of elementary carbon in iron, has been stated to become saturated when the carbon content reaches 2·0 per cent.

The diagram is divided up into a number of regions. As the metal cools from one of these regions to another its constitution should theoretically change; but owing to molecular inertia intensified by rapid cooling, and also to the influence of bodies other than carbon and iron when such are present, these transitions may be partially or even totally suppressed.

The temperature at which these transformations occur in the pure iron carbon alloys may be lowered by the presence of foreign elements such as manganese and nickel.

When the carbon content exceeds 2·0 per cent., but is less than 4·30 per cent., the transformation may be described as follows:—Molten solution of elementary carbon in iron = Molten solution of *eutectic* composition (*i.e*, molten austenite containing 2 per cent. carbon + elementary carbon in solution therein) + solid austenite.

The *eutectic* then freezes, forming austenite + (2 per cent. austenite + graphite).

At the next transformation the following constituents are formed:—Martensite containing ·89 per cent. carbon, cementite, and graphite by lag; for 2 per cent. austenite = ·89 austenite + Fe_3 C. and ·89 per cent. austenite = Fe + Fe_3 C. = martensite.

When the secondary *eutectic* line is reached the transformation becomes

·89 per cent. martensite + cementite + graphite by lag = Pearlite + cementite + graphite by lag.

The reaction

Austenite + (2 per cent. austenite + graphite) = ·89 per cent. martensite + cementite + graphite by lag should theoretically be

Austenite + (2 per cent. austenite + graphite) = ·89 per cent. martensite + cementite

that is, the whole of the graphite should combine with the iron in the austenite to form cementite, which contains 6·67 per cent. carbon; but the graphite exists in sheets of considerable thickness and therefore only in actual contact with the iron molecules at its surface. The total transformation

Graphite + iron = cementite

must therefore depend on molecular activity; it is not surprising that this reaction should lag and the graphite which is formed on freezing should remain as graphite when the metal has become cold.

The transformation to graphite of the elementary carbon held in solution in liquid austenite appears to be relatively slow unless stimulated by the presence of silicon, and for this reason the following transformations sometimes take place:—

Molten solution = supersaturated austenite.
Supersaturated austenite = ·89 per cent. martensite + cementite.
·89 per cent. martensite + cementite = pearlite + cementite.

When the carbon content exceeds 4.30 per cent. the following are the probable transformations that occur:—

Molten solution = molten *eutectic* + graphite.

Molten *eutectic* + graphite = solid *eutectic* + graphite = (2 per cent. austenite + graphite) + graphite.

This 2 per cent. austenite + graphite then passes through the same transformations that occur below the temperature of its formation in the 2 per cent. to 4·30 per cent. carbon alloys.

Theoretically, when the carbon content lies between 2·0 per cent. and 4·3, the constituents, when the metal has been slowly cooled, are pearlite and cementite.

Practically the whole of the graphite formed at the higher temperature is unable, owing to the molecular inertia of solids, to combine with the free iron to form cementite.

The constituents therefore become pearlite, cementite, and graphite by lag (*i.e.*, grey cast iron).

Practically also, owing to the slow transformation of elementary carbon into graphite, supersaturated austenite may be obtained, which on cooling is transformed into pearlite and cementite, white cast iron being the result.

In the description of these various reactions the expressions 2·0 per cent. austenite and ·89 per cent. martensite designate respectively austenite containing 2·0 per cent. carbon and martensite containing 0·89 per cent. of carbon.

HEAT TREATMENT OF STEELS.

The critical points previously referred to have all been obtained during the cooling of the metal.

If, however, the metal be heated back again through this range of temperature, the transformation that occurred on cooling will be gone through in the reverse direction, accompanied by absorption of heat on heating, but at a slightly higher temperature.

For instance, on cooling steel containing ·89 per cent. carbon, martensite changes to pearlite at Ar 1—2—3. On reheating the pearlite changes back again into martensite at a temperature about 30° C. above the Ar 1—2—3.

This point is called the Ac 1—2—3.

Lag.

The transformation from one state to another in passing through a critical point occupies a considerable period of time in the case of metals, and these transformations are opposed by cold.

Molecular inertia, or lag, plays a very important part in the treatment of metals, more especially of steel.

The transformation can be wholly or partially arrested by very quick cooling through the critical range.

Change in Structure due to Heat Treatment.

The changes in structure brought about by Heat Treatment on steel are summarised as follows by Hall :—

He designates the points Ar 1, Ar 2, etc., by the letter V, and the Ac points by the letter W.

1. When a piece of steel, hardened or unhardened, is heated to the temperature W, all previous crystallisation is obliterated and replaced by the finest structure the metal is capable of assuming. (Burnt steel is an exception to this rule).

2. When a piece of steel, having been treated as in 1, is allowed to cool slowly, it retains this fine structure and possesses the finest structure unhardened steel is capable of possessing.

3. When a piece of steel, having been treated as in 1, is quenched, the metal assumes the finest structure that hardened steel is capable of possessing.

4. When a piece of steel, hardened or unhardened, is heated to a temperature above W and allowed to cool slowly, the metal, the crystallisation of which has been obliterated by passing through W, crystallises again, the crystals or grains increasing in size until the temperature V is reached, below which there is no further growth.

5. The higher the temperature above W from which steel is allowed to cool slowly and undisturbedly, the larger the grains.

6. The slower the cooling from a temperature above W the larger the grains.

7. When a piece of steel, hardened or unhardened, is heated to a temperature above W and suddenly cooled, it will be fully hardened; but its structure will be coarser than when quenched after being heated only to W.

8. No change takes place in a piece of unhardened steel that is heated to a temperature below W and either slowly cooled or quenched.

9. When a piece of hardened steel is heated to a temperature below W, the metal is softened; the greater the temperature to which it is raised, the more soft it will become, but no change takes place in the size of the grains.

Change in Structure due to Rolling and Hammering.

The above propositions do not take into consideration the effect on the structure of the metal of such work as hammering or rolling.

Generally speaking the protracted working of a metal at a suitable heat will break up a coarse structure into a fine grained one.

Steel is usually brought to the rolls at a temperature far above Ac 1—2—3, and the grain size is very large at this temperature.

The effect of the rolls is to elongate these grains, and appears to throw the metal crystallographically into unstable equilibrium; the old large grains break up and new small grains form, the new grains assuming the smaller size normal to the lower temperature, and their formation being also assisted by the gradual cooling of the mass as it passes through the rolls.

If the rolling be completed at too high a temperature, the grains broken up by the rolling will again grow and become of a normal size for the finishing temperature.

A high finishing temperature leads therefore to coarseness of structure and consequent brittleness.

A coarse structure thus produced can be got rid of by heat treatment.

Influence of Grain Size on the Mechanical Properties of an Alloy.

Generally speaking the larger the grains the more brittle is the material.

But this may not always be the case. A material may fail under stress from want of cohesion between the grains or from want of cohesion between the particles forming the grains themselves.

The particles composing the grains are similarly orientated in each grain, but the orientation of two contiguous grains is not necessarily the same.

Take the case of a mass consisting of very large grains, the particles in no two contiguous grains being similarly orientated; then, if the cohesion between the particles be less than that between the grains, only those grains of which particles lie parallel to the direction in which the stress is applied will show signs of failure; and supposing rupture to occur in such a grain it will be stopped by grains on either side of it. Such a metal would conceivably be stronger than a metal whose structure was finer but in which the particles were similarly orientated, not only in each grain, as they must be, but throughout all the grains.

Effect of Heat Treatment on the Mechanical Properties of Steel.

Brinnel carried out a careful series of experiments on the properties of various steels when subjected to different heat treatments.

His conclusions are briefly summarised as follows:—

The general effect of annealing is to increase the elastic limit and ductility without any great alteration in the ultimate stress.

Annealing.

Annealing at 350° C. causes a marked rise in the elastic limit, this rise increasing with the carbon percentage.

Above ·34 per cent. of carbon the ultimate stress and elastic limit increases without any appreciable increase in elongation.

At 750° C. there is a further increase in the ductility, but there is a tendency to fall in the elastic limit and ultimate stress, especially in high carbon steels.

Steel shows a tendency to deteriorate when heated above 1,000° C.

Detailed results are given in the following tables:—

ANNEALING.

Carbon. Per Cent.	Ultimate Stress in Tons per Square Inch.					Elastic Limit in Tons per Square Inch.					Elongation per Cent. on 7·08 Inches.				
	Annealing Temperatures.					Annealing Temperatures.					Annealing Temperatures.				
	N	350	750	850	100	N	350	750	850	1000	N	350	750	850	1000
0·09	20·7	20·5	20·9	21·5	21·1	9·4	11·2	10·6	9·2	14·0	26·1	36·0	34·3	33·6	36·3
0·16	29·2	28·3	29·4	27·4	29·9	13·0	16·2	15·9	13·7	17·9	27·2	28·8	30·5	29·0	30·9
0·25	33·0	31·5	30·3	31·5	33·8	13·1	16·2	15·0	13·2	19·1	24·6	26·2	28·3	27·1	26·1
0·34	35·0	34·9	33·4	34·3	36·4	11·9	16·2	15·6	13·8	19·1	23·6	25·6	25·3	26·2	25·9
0·44	41·3	43·8	40·9	40·9	41·7	16·2	18·7	16·9	21·4	21·6	18·9	19·5	21·2	23·8	21·6
0·65	54·4	55·9	51·2	56·3	58·5	18·0	23·0	18·7	25·0	24·2	10·6	11·6	15·0	13·8	12·3
0·79	56·9	60·1	55·4	58·3	59·9	20·0	24·4	21·9	25·1	28·0	10·0	10·8	12·1	12·5	12·2
0·94	62·3	64·9	59·8	58·3	68·3	21·9	27·5	20·0	25·7	30·5	6·7	8·5	10·6	13·4	8·4
1·17	56·2	64·3	60·7	55·8	65·7	22·5	31·2	29·4	25·6	35·4	2·6	3·6	9·8	15·1	4·1

N = Normal rolled bar.

Temperatures are in degrees centigrade.

CHEMICAL COMPOSITION OF TEST BARS.

Carbon. Per Cent.	Silicon. Per Cent.	Sulphur. Per Cent.	Phosphorus. Per Cent.	Manganese. Per Cent.
0·09	0·005	0·020	0·026	0·10
0·16	0·453	0·010	0·030	0·26
0·25	0·299	0·012	0·029	0·41
0·34	0·266	0·015	0·026	0·49
0·44	0·275	0·018	0·029	0·46
0·65	0·275	0·011	0·028	0·49
0·79	0·378	0·011	0·029	0·20
0·94	0·289	0·013	0·025	0·25
1·17	0·313	0·010	0·027	0·21

Quenching from 750° C. in Water.

Generally there is very little alteration in ultimate stress, etc., by quenching steel from 750° C., whether it be subsequently reheated or not.

Quenching from 850° C. in Water.

Quenching from 850° causes a decided increase in the ultimate stress in all steels containing ·44 per cent. carbon or less. There is however a corresponding fall in elongation, the loss being greater for the high carbon steels. The elastic limit also falls except in the case of steels with less than ·1 per cent. carbon.

On reheating the quenched bars to 350° C., those containing ·16 per cent. of carbon are practically unchanged.

Steels containing from ·25 to ·44 per cent. carbon so quenched show on reheating an increase in ultimate stress and elastic limit as compared with the quenched steel.

There is no advantage obtained by reheating quenched steels to 650° C. except in the case of those of high carbon content.

Generally speaking, as regards water hardening the greatest improvement, as shown by tensile tests, is obtained by quenching in water from 850° C. and subsequent reheating to 550° C.

Quenching from 1,000° C. in Water.

Steels containing from ·16 to ·34 per cent. carbon deteriorate in all respects when quenched from 1,000° C. in water.

On reheating steels so quenched the ultimate stress and elastic limit are high, but the ductility remains low.

The general effect of quenching from any temperature in oil heated to 80° C. is to produce an increase in ultimate stress somewhat less than is caused by quenching in water, but without the accompanying loss in elastic limit. Quenching in Oil.

The actual temperature employed for annealing varies considerably, the more usual ranges being from 750° C. to 850° C. Practical Annealing.

There are many practical difficulties in treating large masses. Considerable care is required to ensure heating throughout and regular cooling, and it is difficult to attain these requirements when dealing with hundreds of tons of material per day.

Large forgings and castings require annealing by themselves in a furnace which should receive constant supervision.

As regards oil quenching, steel for guns, axles, etc., is usually heated to a temperature of about 800° C., quenched in oil at 20° C., and reheated to about 550° C.

The diagram on *Plate* III. is intended to furnish a general idea of the relations existing between the carbon content and the mechanical properties of slowly cooled or pearlite series of the iron carbon alloys.

The tenacity and ductility curves can only be an approximation, as these properties are influenced by the presence of constituents other than iron and carbon; they apply approximately to ordinary commercial material, such as girders, angles, plates, etc.

The diagram on *Plate* IV. shews the relations between the constituents and the physical properties of cast iron containing 4 per cent. carbon, as affected by the distribution of the carbon between the combined and the graphite conditions.

From these various considerations the intimate relation existing between the microstructure and the mechanical properties of steel become evident. *Résumé.*

By comparing the microstructure of a specimen of steel with those obtained under known conditions, the mechanical and heat treatment, which the material represented by such a specimen has undergone, can be very accurately gauged.

Familiarity with the subject, both theoretical and practical, is however necessary before accurate results can be obtained.

There now exist very many valuable works in which recent investigations are recorded, and it is only by following as far as possible, and repeating the experiments so made, that experience can be acquired.

INFLUENCE OF SILICON, SULPHUR, PHOSPHORUS, MANGANESE, ETC., ON THE PHYSICAL PROPERTIES OF STEEL.

The effect of the presence of various substances in steel varies considerably with the carbon content and also with the heat treatment.

The following remarks must be taken as applying generally only, as it is not possible to deal with the question in detail in a short paper.

Silicon in Mild Steel.

Silicon rarely exceeds ·10 per cent. in mild steel, although the proportion may be increased up to ·7 per cent. without injuring the properties of the steel.

Its presence in a larger proportion than ·10 per cent. in Bessemer steel points however to the fact that during manufacture a temperature was reached at which the carbon is oxidised before the silicon, resulting in a "hot blow"; and consequently, the steel being cast at too high a temperature. Such steel is unreliable.

If silicon exceeds about 2 per cent., a peculiar crystallisation occurs both in forged and cast steel, rendering the material extremely brittle.

Silicon is prejudicial to welding when in excess of ·7 per cent. It increases the fusibility of steel but decreases its fluidity.

As regards the high carbon steels the presence of silicon to the extent of even ·6 per cent. is in many cases said to improve the quality.

Sulphur.

The influence of sulphur on the tensile strength and ductility of steel, when it is present in quantities of less than ·1 per cent., is very slight.

Steel for welding should not contain more than ·06 per cent. sulphur or red shortners will be apparent.

Sulphur has no direct influence in the cold on steel; but when the metal is hot, as when rolling, cracks are developed if the sulphur content is high; these cracks close up as the material leaves the rolls and are imperceptible, but act as starting points for rupture when the material is subjected to stress.

The presence of manganese decreases the tendency to shortners due to a high sulphur content.

Sulphur, when present in large quantities, forms a mesh-like structure between the grains, consisting of sulphide of iron. This sulphide has a lower melting point than the iron grains, and is semi-fluid when the material is worked at a high temperature.

Manganese breaks up this structure to a great extent, and globules of a sulphide of manganese result; these are distributed more evenly throughout the material.

Phosphorus.

Phosphorus has a most prejudicial influence on the physical properties of steel.

As regards hot working the effect of phosphorus, even when present in quantities as high as ·25 per cent., does not produce red shortners, although when cold such a material would be extremely brittle.

Phosphorus should never be allowed to exceed ·06 per cent. for commercial purposes; when present in excess of this amount it produces a tendency to brittleness.

In high carbon steels the effect of its presence is more marked, and it should not exceed ·03 per cent. in good steel.

Manganese.

Manganese is added to steel during manufacture to deoxidise the decarburised metal. Its effect on the physical properties varies with the carbon content.

In the case of mild steel and rails the less manganese the metal contains the better, provided it is present in sufficient quantity to ensure sound ingots and freedom from red shortners. This result can be obtained with about ·5 per cent. manganese, and it should not exceed ·8 per cent.

Manganese tends to increase the tensile strength and reduce the ductility.

Its influence on high carbon steels is more marked. When present in excess of ·5 per cent. it is liable to cause fracture on quenching.

The influence of large quantities of manganese, such as 5 per cent. and over, cannot here be dealt with as these materials are special steels.

Arsenic.

Arsenic up to ·1 per cent. does not materially affect steel for commercial purposes when it is not required for welding.

Copper.

The influence of copper on steel has been greatly exaggerated. Its presence up to ·5 per cent., or even more, has no serious influence on the properties of steel.

Nickel,
Chromium,
Vanadium,
etc.

The influence of nickel, chromium, vanadium, etc., comes under the head of special steels and cannot be dealt with within the limits of these notes.

PART II.—MICROPHOTOGRAPHY.

Apparatus Required.

The choice of a suitable apparatus for microphotographic work is not very difficult. The question of price has the greatest influence on the selection.

The following is a list of apparatus with which the photographs reproduced have been taken. The amount of money available was about £100 and on this basis the selection was made. It is thought that this is about the minimum expenditure advisable if good results are required ; some of the leading manufacturers in England have spent at least ten times this amount on their outfit.

Speaking generally, the better the apparatus the more satisfactory the results.

	£	s.	d.
Microscope, designed by J. E. Stead, specially strong for rough work	21	0	0
Mechanical stage	0	10	0
Objectives, 3″	1	13	0
1½″	1	13	0
½″ N.A. 0·50	2	0	0
¼″ N.A. 0·88	2	17	0
⅛″ Apochromatic oil immersion	8	8	0
Ordinary ocular, No. 3	0	6	0
,, ,, No. 1 (included with microscope)		—	
No. 4 Compensating ocular	2	0	0
Projection eyepiece	1	0	0
Aplanatic stand condenser, with iris diaphragm (Nelson design)	4	0	0
Hand magnifier × 6	0	15	0
Parabolic reflector	1	3	0
Prism illuminator	0	18	6
Vertical ,,	0	10	6
Paraffin lamp	0	12	0
Acetylene lamp, with Dreadnought generator	4	5	0
¼-plate camera	3	10	0

(The above were obtained from Messrs. Swift & Son, 81, Tottenham Court Road, London, W.).

	£	s.	d.
Foot-power polishing machine	8	10	0
Diamantine	0	2	0
Emery discs (Nos. 00, 000, 0000)	0	4	0
Plasticene	0	1	0
Jewellers' rouge	0	2	0
Brass mounting rings	0	2	6
Parchment, broad cloth and chamois leather discs	0	2	6

(The above were obtained from Messrs. Carling & Son, 50, Grange Road, Middlesbrough).

	£	s.	d.
To facilitate working a small bench, fitted with a hand-power hack saw, vice and emery wheel, was obtained from the last-named firm for the sum of	10	0	0
The following reagents are required, the quantity varying with the amount of work done; the cost of sufficient for several months' work would not exceed	1	0	0

Chloride of iron ($Fe_2\ Cl_6$).
Picric acid.
Nitric ,,
Hydrochloric ,,
Alcohol, absolute.
Oil, lubricating instruments.
Methylated spirit.
Paraffin oil.

The following are required for heat treatment experiments:—

	£	s.	d.
1 No. 4 Muffle furnace with oil tank and foot blower	6	15	0
2 Muffles for ditto	0	7	0
2 Crucibles, No. 00 fireclay	0	0	6
Ditto, plumbago	0	1	6
1 Pyrometer, comprising 1 Platinum Rodium couple, 60 C.M. long, in steel tube, with galvanometer reading from 0 to 1,600° C.	12	17	6

(The reagents, muffle, and pyrometer were obtained from Messrs. Townson & Mercer, Bishopsgate, London).

In addition to the above a few tools such as :—

	£	s.	d.
Files, dead smooth, flat, 6″ and 10″.			
,, rough, 12″.			
,, second cut, 12″.			
Hammers, riveting, 12oz.			
,, smith's, 31lbs.			
Stamps, steel, for metal letters, $\frac{1}{8}$″ set, and figures, $\frac{1}{8}$″ set.			
Measures, glass, grad. 10oz.			
Saws, cutting metal, 10″, with spare blades.			
Cloth, emery, sheets Nos. L, F, 0, and 00.			
Also a dark room with apparatus for developing negatives and for printing, say ...	5	0	0
Total cost	£102	6	6

The above list is rather long, but all the stores enumerated are really necessary if any research work is undertaken.

Illustrated catalogues can be obtained from the firms mentioned, which render unnecessary the reproduction of plates showing the apparatus used.

The camera designed by Mr. Stead consists of a light coned shape body fitting on to the top of the microscope with no other support. The immense leverage thus obtainable when placing the dark side in position was found frequently to alter the focus. Mr. Stead reports that this is not the case with the camera (of similar type) in his possession. This difficulty was overcome by placing the camera on a tripod and connecting it to the microscope by a flexible joint.

For work at large magnification a horizontal leather bellows camera with extra long extension is recommended.

Better results can be obtained with a low power objective and long camera length than with a high power objective and a short camera.

A cabinet specially constructed for holding heavy specimens is recommended as a useful addition to the outfit.

The apparatus enumerated is suited for work where gas and electric power are not available. Should the latter be obtainable an arc lamp can be substituted for the acetylene lamp, with the result that the length of exposure is considerably reduced and better photographs result. Also the polishing machine, emery wheel and hack saw can be driven by a small motor.

A power drive for these machines is advantageous as greater freedom for working is obtained, and the preparation of the specimens can be more rapidly carried out.

Preparation of Specimens for Examination.

Specimens for examination should be of about the following dimensions, viz. :—$\frac{3}{8}''$ by $\frac{3}{8}''$ by $\frac{1}{4}''$ in depth. If smaller than this, they become difficult to hold in the succeeding operations, and if of greater dimensions there is a difficulty in obtaining ultimately a true flat surface free from scratches.

Plain Polishing.

The specimen should be sawn cold from the material the structure of which it is desired to investigate. It should then be ground true on one face on an emery wheel or with a smooth file, and the edges rounded off; sharp edges are apt to tear up the cloth on which the final polishing is carried out.

After leaving the emery wheel the specimen is rubbed by hand on emery paper. This rubbing should be carried out backwards and forwards in a straight line, so that the scratches all lie in one direction.

The specimen should then be turned through 90°; and the rubbing continued until all the previous scratches are removed, and a new set formed, lying all in one direction, at right angles of course to that of the previous scratches. The pressure at each succeeding rubbing should be gradually reduced.

The whole series of emery papers down to No. 00 should thus be worked through, the scratches produced by each succeeding paper being of course finer and finer.

The next rubbings, viz., those on the Nos. 000 and 0000 emery papers, can be carried out on the polishing machine. These papers are mounted on flat wooden discs and secured by brass rings pressed over the paper down on to the bevel edge of the circular disc. The disc is rapidly revolved by means of a foot pedal suitably geared to a platform on which the disc rests. The specimen should be kept moving across the surface of the disc so that the scratches may be alternately in two directions.

The scratches produced by the No. 0000 paper should only be discernible by means of a magnifying glass.

The final polish is carried out on the polishing machine, on wet cloth with diamantine powder, parchment with rouge, or chamois leather with rouge, the two last both moistened with water or (in the latter case) occasionally with oil; the cloth, leather or parchment is fastened to the wooden discs in the same way as the finer emery papers Nos. 000.

The specimen should be carefully washed in water to remove any grains of emery before the final polishing.

For steel and iron two layers of broad cloth, of fine texture without ribs, are recommended, the diamantine being placed between the two layers and water allowed to drip on the disc during the polishing.

For brass, bronzes, and similar comparatively soft alloys, good results can be obtained by using two layers of chamois leather with rouge between and moistened with refined instrument oil.

The specimen thus treated should have an absolutely true surface, which should be entirely free from scratches.

This process is known as plain polishing.

There is, however, amongst various workers a diversity of practice differing but slightly from the above. Each individual must ascertain for himself what style best suits his personality. I prefer to do all my polishing holding the specimen between my fingers; but many use a holder (a small type of vice) secured in an automatically-oscillating head over the disc on the polishing machine, and fitted with an adjustable spring so that the pressure can be varied.

Relief Polishing.

If the plain polishing on a cloth block that has a soft pad under it be much prolonged in the case of a specimen containing two substances of a different degree of hardness, the soft one will be worn away more rapidly than the harder one, with the result that a series of surfaces bordered by inclined edges will be produced.

This is called relief polishing.

It is very useful in many cases; owing to the difference in level between the planes formed by the hard and soft substances, the hard substances can be differentiated from the soft ones under the microscope.

Drying.

After plain or relief polishing the specimen should be carefully dried.

In the case of wet polishing a soft piece of silk gauze may be used to wipe the polished surface, which should then be placed in a hot air bath. (A methylated spirit lamp and an old tobacco tin form a cheap and effective hot air bath). The temperature of the bath should not exceed about 80° C., and the specimen should not be kept for too long a period therein or heat oxidation tints may result.

After polishing with oil and rouge great care is needed to thoroughly get rid of the oil. Washing in alcohol and wiping repeatedly with a soft silk gauze rag is recommended, followed by washing in water and drying in the hot air bath.

At all stages of the polishing great care should be taken that the specimen, and the surfaces on which it is rubbed, are free from grit, dust, emery from a previous block, tobacco ash, etc.

The final blocks should be kept in air-tight cases when not in use.

Etching.

Plain and relief polishing do not develop all the structures that exist in many alloys and in steel, and it is therefore desirable to bring them out by means of etching. For this purpose various reagents are used, the following being the most important.

Nitric acid is commonly used. Osmond uses both a 20 per cent. and a 2 per cent. solution of 1·33 specific gravity acid.

Sauveur etches steel by immersing it for a few seconds in nitric acid of 1·42 specific gravity and then washing in water. This latter method gives very excellent results, as the iron remains inactive under the strong acid until the water is added, the depth to which the etching is carried being thus under control.

After etching, the specimen should be carefully washed in alcohol and in water; it should then be carefully dried in the hot air bath.

Iodine is also used as an etching reagent for steels. Tincture of iodine made up as follows is used for general work:—

add 1.25 grains iodine
and 1·25 grains potassium iodide
to 1·25 C.C. of water
and make up to 100 C.C. with alcohol.

Picric acid is becoming more and more largely used for etching iron and steel. A 5 per cent. solution in alcohol will give satisfactory results.

Its action is easily controlled; and has the advantage of leaving ferrite untouched, whilst nitric acid frequently eats out the grain boundaries as well as the crystal boundaries, causing ferrite to assume a speckled appearance.

Chloride of iron is invaluable for etching bronzes, brass, or any alloy containing copper.

The aqueous solution used should be made up of:—

$Fe_2 Cl_6$ (chloride of iron) 10 per cent.
H.C.L. (hydrochloric acid) 1 per cent.

Polish attack. Other methods of etching.—The structure of steel can be developed by the "polish attack," that is to say by substituting for diamantine or rouge a substance that will react on the constituents of steel.

Precipitated sulphate of calcium and a liquorice infusion, or a 2 per cent. solution of ammonium nitrate on parchment may be used.

This method is not so reliable as etching with picric acid, and is not recommended for ordinary work.

Heat Tinting The specimen, after being plain polished and carefully dried, is heated until the oxidation tints appear. The different constituents of steel and bronze assume the tints at progressive rates and may therefore be readily differentiated under the microscope.

Generally speaking considerable experience is required in order to know which reagent will give the best results in particular cases.

The depth to which the etching should be carried is also of importance.

The picric acid 5 per cent. solution in alcohol will develop a pearlite structure in about a quarter of a minute.

APPEARANCE OF THE CONSTITUENTS OF IRON CARBON ALLOYS UNDER THE MICROSCOPE.

Ferrite. On plain polishing ferrite has a specular appearance. On polishing in relief the appearance is granular, resolving into polyhedric grains, some in relief and some sunken.

The polish attack renders the above appearances more pronounced.

Nitric acid marks the crystal boundaries, but its effect in colouring the grains forming the crystals is very complex.

Picric acid has practically no effect on ferrite leaving it white or nearly white.

Cementite. Cementite is the hardest constituent of steel, and is therefore readily isolated by relief polishing. It remains brilliantly white under the action of the various etching reagents.

Pearlite. Pearlite is coloured rapidly by the etching reagents.

The actual colour is difficult to describe. Generally speaking it is brown, but the colour is qualified by a peculiar bluish pearly iridescence, whence its name.

Pearlite may be either granular or laminated. In the former case its structure cannot be resolved under the powers at present obtainable. In the latter it consists of alternate plates of ferrite and cementite, generally curved and lying differently orientated in each crystal.

Martensite.

Martensite may be readily recognised by its structure; it consists of numbers of fine needle-like fibres triangularly orientated.

It is coloured light brown by the etching reagents, the needle-like structure being rendered visible.

The smaller the carbon content the longer and larger are the martensite needles.

Austenite.

Austenite is not coloured by the etching reagents, with the exception of iodine, which turns it brown.

It is difficult to differentiate it from hardenite, as the etching reagents have a very similar effect on both. A 10 per cent. solution of H.C.L. however colours hardenite but not austenite.

Austenite is generally obtained with hardenite, the formation consisting of parallel bands of hardenite lying in two directions at an oblique angle, the spaces between the bands being filled with austenite.

Troostite.

Troostite is softer than martensite, and can therefore be differentiated from it by polishing in relief.

The structure of troostite is developed by etching; it occurs as an irregular marble-like structure of a brown colour.

It is nearly amorphous, and slightly granular.

Sorbite.

Sorbite is rapidly coloured brown by the etching reagents; it colours more readily than troostite.

It is often difficult and sometimes impossible to trace its transition into pearlite.

Sorbite, sorbitic pearlite, and granular pearlite are often found merging the one into the other.

Graphite.

Graphite is usually found in large flakes appearing as curved lines on the polished surface of a specimen.

The flakes are sometimes rubbed out in polishing, leaving on the surface fissures which become filled with rouge.

The polished surface of grey iron occasionally exhibits projecting lustrous ribs of graphite.

Slag.

Wrought iron frequently contains as much as 2 per cent. of slag.

It is readily recognized therein as occurring in fibrous masses lying in the direction of rolling. They appear as long thin masses in sections cut longitudinally, and as small rounded masses in transverse sections.

In steel the occurrence of slag is much less frequent and should be practically entirely absent.

Cavities and Gas Bubbles.

Cavities and gas bubbles are confined for the greater part to pig iron and to portions of steel ingots.

Cavities are produced through the contraction of the mass of an ingot during cooling.

Gas bubbles are formed by the imprisonment of gas generated during cooling, the steel being in a pasty or viscid condition preventing their escape to the surface.

Cracks and Flaws.

The surface to be examined for cracks and flaws must not be ground down as this might obliterate small cracks. The best way to treat the surface is to rub it smooth with Nos. 000 and 0000 emery paper, finishing up with chamois leather and rouge, and etching with 1 per cent. solution nitric acid.

The surface so treated can then be examined, but only a very low magnification can be employed.

Slip Bands.

Slip bands are the forerunners of flaws or cracks.

If steel be put under stress until plastic deformation occurs, slip bands are produced.

In the case of ferrite each crystal contains a number of grains similarly orientated. Such a structure will possess cleavage planes similar to those found in larger crystals; the plastic yielding of such crystals takes place by means of slips along the cleavage planes.

The whole material, when subjected to a stress causing plastic deformation, must of necessity undergo alteration in shape, and to this new shape the original crystals must adapt themselves. According to present theory they do so by the sliding of the grains over one another, on at least three sets of cleavage planes.

These slip bands are found to extend right across a crystal, and several parallel bands are found in each crystal. If the deformation be carried further, one or more of these bands becomes further developed and may then extend to adjacent crystals, but taking up a new direction dependent on the orientation of the grain in that crystal.

There is a very interesting fact connected with slip bands, namely that, when a specimen has been strained beyond the elastic limit, it can be restored either by lapse of time or immediately by immersion for a few minutes in boiling water. That is to say a healing up or recementing can take place between the grains where the slip band has been produced.

On subjecting a specimen to a rapidly reversing stress, slip occurs backwards and forwards over the same faces of the grains, a veritable grinding action being set up.

Slip bands are difficult to observe under the microscope. The heat generated in polishing is sufficient to cause healing up, and therefore they can only be observed in specimens that have been subjected to stress after the polishing is complete.

EXAMINATION OF THE COPPER-TIN ALLOYS.

Copper Tin Alloys.

The copper rich portions of the Cu Sn alloys oxidise more rapidly than the tin rich portions, and therefore the structure can be brought out by heat tinting.

The chloride of iron solution readily brings up the pattern, but in some cases the light and shade are reversed.

Chilled alloys should not be heat tinted; being in unstable equilibrium they are liable to change of structure on heating.

Bronzes containing Lead.

The lead distribution can be very clearly ascertained by heating the specimen until the lead stands out in spheroidal globules on the polished surface. If these globules are flattened out by pressure against a piece of plate glass they show up dead white under the microscope, but their size is of course greatly increased in the plane of the polished surface.

MOUNTING, PRESERVATION AND IDENTIFICATION OF SPECIMENS.

Mounting Specimens.

When the specimen has been duly prepared the most usual procedure is to mount it temporarily on a glass slide with plasticene.

To effect this the specimen is laid, polished face downwards, on a piece of plate glass; and a brass ring, which has its two faces made exactly parallel, is placed over the specimen, the ring being about $\frac{1}{8}$ inch deeper than the specimen. The glass slide, on which a small lump of plasticene has been placed, is then pressed down on the ring until the glass is in contact with its face, the specimen being then embedded in the plasticene.

The glass slide, with the specimen adhering to it by means of the plasticene, is then lifted off the ring and is ready for examination.

As the two faces of the ring are parallel the surface of the specimen will be parallel to the stage of the microscope when the slide is laid in position for investigation.

This is a very ready and quick method of mounting; it also has the advantage of doing away with the necessity of grinding up two opposite faces of the specimen so that they are parallel to each other.

Preservation.

For ordinary work the finished etched specimen can be kept for a few weeks unchanged; and, if kept in dry, air-tight cases, this period can be prolonged to months before the surface will commence to tarnish.

It is often desirable to preserve for longer periods standard specimens or those of special interest. This can best be done by covering the surface of the specimen with a thin coat of zapon or any celluloid varnish that is soluble in alcohol. Zapon varnish is a solution of guncotton in amylacetate.

The use of cover glasses is not recommended as they are unsuitable for opaque specimens requiring vertical illumination.

The zapon varnish has two great advantages, viz. :—the structure of the specimen can be examined through a thin coat of such varnish; and, if required for photographic purposes, the coat of varnish may be dissolved in alcohol, leaving the surface of the specimen perfectly clean.

Identification.

A record of all specimens examined, with a complete history of their properties, composition and treatment, should be kept.

The results obtained under the microscope and photographs can then, if necessary, be added to each individual record.

Each specimen should have an identification letter or number assigned to it, and this identification mark should be stamped both on the specimen itself and on the material from which it was sawn or cut. The position and plane from which the specimen has been cut should be also recorded.

All negatives and prints should be similarly marked; and a record kept, giving the magnification, etching reagent employed, exposure, etc.

Information under all the following heads is therefore required, and should always be recorded where obtainable.

EXAMPLE.

Identification Mark	S. 22.
Material	Cast steel flywheel boss for 10 H.P. nominal traction engine, W.D. No. 20.
Mechanical Tests	Ultimate tensile strength in tons per sq. in., 29·59; Elongation per cent. on 2 ins., 37·0; Contraction of area per cent., 53·0.

Appearance of fracture and bending tests not recorded.

Result of Analysis	C, 0·28 per cent.
	Mn, 0·51 per cent.
	Si, 0·34 per cent.
	S, 0·031 per cent.
	P, 0·058 per cent.
Heat Treatment	(not recorded).

Microscopic Examination.

Specimen cut from Test piece.

Section—Transverse.
Etched picric acid.
Constituents—Pearlite and ferrite.

Normal.

Photograph × 100 diameters.
Exposure 6 minutes.
Illumination—Vertical.
Plates—Ilford special rapid.
Objective—$\frac{1}{2}''$.
Eyepiece—Projection.

MICROSCOPIC APPARATUS.

Metallic objects, being opaque, cannot be examined by transmitted light; special apparatus for vertical or oblique light are therefore required.

Oblique Light.

Oblique light can only be used with low power objectives, as its use necessitates the employment of a parabolic reflector, so placed that horizontal beams of light passing between the objective and the specimen may be reflected obliquely across the surface to be examined.

If such surface be truly flat no light will be reflected into the objective, the object remaining black; but if any difference of level exist, the light striking the edge of any plane in relief will be reflected into the objective.

Oblique illumination is therefore useful in determining what constituents are in relief and which portion of a structure is broken up.

Vertical Illumination.

For low powers an ordinary cover glass (as used for microscopic slides), mounted at 45° to the vertical in a cylinder with a hole on one side to admit the light and having its surface blackened on the inner side opposite to the hole, forms an effective reflector.

For higher powers a prism reflector is necessary. In using a prism reflector very careful adjustment of the light is required in order to avoid unequal illumination and flare.

Source of Light.

For ordinary work a paraffin lamp is sufficient; but for photography a Welsbach gas-burner or an Acetylene lamp is required, and with higher powers the electric arc has to be used when good and rapid results are desired.

PHOTOGRAPHY.

Focusing.

The object should be carefully focused under the microscope in the usual way; the camera should then be put in position, and the final focusing carried out by means of the fine adjustment screw, the correctness of the focus being ascertained by means of the No. 1 eyepiece placed in the plane that the face of the photographic plate will eventually occupy.

Exposure.

The length of exposure varies with the illuminating power, the objective used, and the camera length.

With an acetylene lamp—using ½″ objective, the projection eyepiece, and a camera length such that a magnification of 100 diameters is obtained—an exposure of from 6 to 8 minutes is required for Ilford special rapid plates.

The length of exposure varies according to the amount of light reflected by the object, and by its colour.

A pearlite area, etched with picric acid, will require nearly double the exposure necessary in the case of ferrite or cementite similarly etched.

A yellow bronze again requires a longer exposure than pearlite.

Magnification.

The magnification required depends on the coarseness or otherwise of the structure.

The structure of mild steel, wrought iron, and cast iron can be studied generally at from 50 to 200 diameters.

Special steels, that have been subjected to a heat treatment conducive to fine structure, often require magnifications of from 1,000 to 2,000 diameters before that structure can be resolved; and that of some nickel steel for armour plates is not resolved at 2,000 diameters.

For ordinary purposes the majority of the results required can be attained at about 100 diameters, resorting to 500 diameters in a few special cases.

A Table of magnifications, obtained with each objective and eyepiece at various camera focal distances, should be prepared. This can be done by placing a micrometer slide under the microscope; then, by focusing carefully on a piece of ground glass placed in the plane which the surface of the photographic plate will occupy, the exact magnification under the various conditions is obtained by measuring the distance between the divisions of the scale as thrown on the ground glass and comparing this length with the original.

Generally there are many minor difficulties that will be encountered when commencing microphotography, these troubles varying with the type of apparatus employed. The more expensive the plant the fewer the difficulties.

It is only by experience and patience, and by keeping a detailed record of work done, that good results are ensured.

Vibration is a frequent source of vexation. Very few buildings situated in towns are free from vibration caused by street traffic, etc.

As regards the specimens themselves, scratches filled with rouge, unequal etching, etching with an unsuitable reagent, over or under etching, examination under too high or too low a power, incomplete examination, examination of a specimen taken from an unrepresentative portion of the material, etc., are all causes that may lead to erroneous conclusions.

If anything unaccountable or extraordinary is observed in a specimen, definite conclusions should only be drawn very guardedly; a large number of specimens cut from the same material should be examined in order to verify the unusual structure observed.

In the case of rolled steel, such as girders and especially rails, at least three surfaces should be examined, viz., one transverse section, and two longitudinal sections cut from two planes at right angles.

As regards rails, specimens should be cut from the head (both edge and centre), from the flange, and from the web.

PART III.

DESCRIPTION OF PHOTOGRAPHS REPRODUCED.

The photographs, with the exceptions of Nos. 1 and 2, which are reproduced from Osmond's notes on the microstructure of the iron carbon alloys, have been taken by me during the ordinary course of work and have not been specially prepared. They are selected from a large number of photos as being illustrative of various types of structure.

I find that I can now saw off, polish, examine, and photograph specimens at 180 diameters at the rate of from three to four per hour, not including the time spent in developing the negatives and in printing.

If finer and better work is required at a greater number of diameters a very much longer time is needed for its production.

1. ... Magnification, 1,000 diameters. Cementation steel, carbon content 1·60 per cent. Polish attack. Very largely developed pearlite and cementite.

The white fibres with black borders in the pearlite areas are cementite, these fibres being separated by ferrite, also white; the large white masses are cementite.

The black borders of the cementite in the pearlite are the rounded edges of the cementite, which is standing up in relief above the ferrite.

2. ... × 1,000. Steel heated to 1,000° C. and quenched in a freezing mixture below 0° C. Etched 10 per cent. H.C.L. Austenite and hardenite, the latter being the dark portions.

3 ... × 500. Steel heated to 900° C. and quenched in water. Carbon content 1·4 per cent. Etched picric acid. Cell masses of martensite bounded by troostite (dark). The grains are bounded by fine veins of cementite.

. ... × 50. As for No. 3.

Being at a smaller magnification the general structure is more clearly shewn.

. ... × 50. Steel reheated at 900° C., cooled slowly to Ar_1, then cooled quickly. Etched H.N.O.$_3$. Partially segregated pearlite (dark) and ferrite (white).

The boundaries of the ferrite grains are clearly shewn. Carbon content ·16 per cent.

. ... × 50. Steel containing 1·4 per cent. carbon.

This is an example of sorbite with laminated pearlite, the white grain boundaries being cementite.

Etched 5 per cent. solution picric acid in alcohol.

. ... × 180. Nickel steel armour plate.

Ultimate tensile strength 45 tons per sq. in. with an elongation of 24 per cent. on 2 ins.

Etched picric acid.

The structure is too fine to be resolved at this magnification.

. ... × 180. Steel boiler plate.

Ultimate tensile strength 28 tons per sq. in. Carbon content ·16 per cent. Pearlite and ferrite.

Etched picric acid.

This photo clearly shows the direction of rolling.

Nos. 9—10—11—12 and 13 are all taken from a single section of rail, and illustrate clearly the different grain sizes induced by various rates of cooling and by the amount of work performed on each portion.

A sample from this rail on analysis shewed the following constituents :—

C	...	·347 per cent.
Si	...	·069 per cent.
Mn	...	·375 per cent.
P	...	·060 per cent.
S	...	·044 per cent.
Cu	..	·160 per cent.

9. ... × 180. Section from the web.
Etched picric acid.
Pearlite and ferrite.

0. ... × 180. Section from the flange.
Etched picric acid.
Pearlite and ferrite.

11. ... ×180. Longitudinal section from the upper edge of the head.
Etched picric acid.
Pearlite and ferrite.

12. ... ×180. Section cut longitudinally from the centre of the rail head.
Etched picric acid.
Pearlite and ferrite.

13. ... ×180. Transverse section from the centre of the head.
Etched picric acid.
Pearlite and ferrite.

14. ... ×180. Wrought iron shewing slag.

15. ... ×180. Chilled cast iron. Etched picric acid.
Massive cementite and pearlite.

This is a very interesting specimen as it clearly shows both the primary and secondary *eutectic*.

In this case supersaturated austenite was formed on solidification; on further cooling, the austenite split up into martensite and cementite, and at Ar 1 the martensite broke into the secondary *eutectic*, viz., pearlite.

The structure thus consists of massive cementite, pearlite, and massive cementite with small masses of pearlite embedded in it; this latter is the primary *eutectic*, and very often resembles closely the phosphide *eutectic* in appearance. A small proportion of phosphide *eutectic* is also present.

The pearlite is of course the secondary *eutectic*.

On analysis the iron was found to contain :—

C	...	4·60 per cent.
Mn	...	0·070 per cent.
Si	...	0·078 per cent.
P	...	0·108 per cent.
S	...	0·02 per cent.
Cu	...	0·018 per cent.

Cr and Ni trace or none.

16. ... ×180. Grey cast iron. Etched picric acid.

The graphite is well developed (the dark irregular curved lines).

The pearlite is also clearly recognised and under a higher power appears similar to that shown in Photo 1.

The specimen was taken from the piston of a 25 B.H.P. Oil engine.

The following constituents were found on analysis :—

C	...	2·98 per cent.
Si	...	2·12 per cent.
Mn	...	0·282 per cent.
P	...	1·18 per cent.
S	...	0·156 per cent.
Cu	...	0·015 per cent.
Wi	...	0·10 per cent.
Cr	...	Trace or none.

7. ... × 50. Bronze containing lead. Etched $Fe_2 Cl_6$.

The specimen was heated after polishing until the lead exuded from the surface, and was then pressed against a sheet of plate glass; the round white portions are the lead.

This bronze was cast in sand; if cast in a chill the lead is found to be more finely and evenly divided.

8. ... × 180. Experimental bronze (containing lead and nickel) for traction engine bearings.

The copper and tin content were 81 per cent. and 15 per cent. respectively.

This photograph is typical of selective freezing and the land-locked structure, the white portion being the *eutectic*.

9. ... × 60. Etched picric acid.

This photograph is from a single bar of steel containing ·16 per cent. carbon.

The bar was annealed in a slag ball; one end was then heated to nearly melting point while the other end was kept at air temperature; the bar was then cooled fairly quickly but not quenched.

The photograph was taken on a number of plates each overlapping slightly the one next to it, the prints were cut to form a continuous photograph.

The cool end of the bar shewn in the right half of the photograph consists of ferrite and well-developed sharply-defined pearlite (dark).

About the centre of the photograph the edges of the pearlite become ragged, and gradually as the left of the photo is approached these areas appear more and more broken up until, on the extreme left, the structure consists of very fine pearlite and ferrite, assuming a mottled appearance, the structure being too fine to be resolved at this magnification.

The black rounded spots on the left of the photo are flaws.

The splitting up of the original very coarse structure on reheating can thus be clearly traced.

BOOKS RECOMMENDED.

The following books are recommended as works of reference, and for study before commencing practical work:—

(1). *The Metallurgy of Steel*, by F. W. Harbord, with a section on the Mechanical Treatment by J. W. Hall. Edited by Sir Roberts-Austin. (Charles Griffin & Co.).

(2). *Iron, Steel, and Other Alloys*, by H. M. Howe. (Sauveur & Whiting, Boston, Mass., U.S.A.).

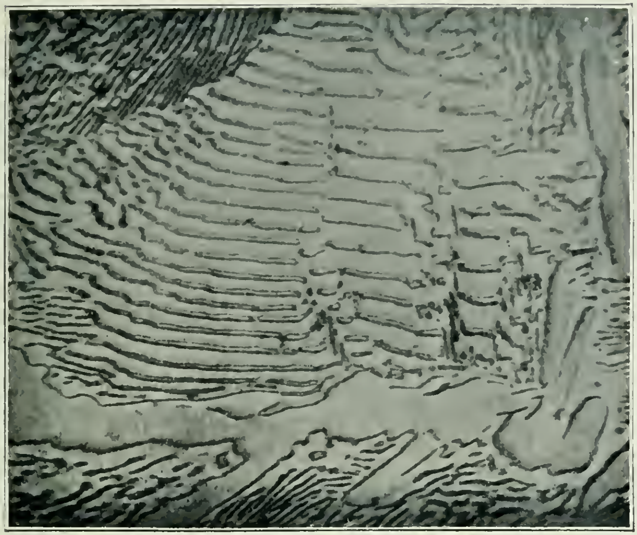
(3). *Siderology*, by H. F. V. Juptner. Translated by Charles Salter. (Scott, Greenwood & Co.).

(4). *Contribution à l'étude des Alliages*, 1896—1900. Société d'encouragement pour l'Industrie Nationale (Typographic Chamerot et Renouard, 19, Rue des Saints Péres, Paris), 1901. (This work is in French and has not been fully translated. It contains, amongst other valuable contributions, a paper by Osmond entitled *Méthode Générale pour l'analyse Micrographique des aciers au carbone*).

(5). *Philosophical Transactions of the Royal Society of London.* Series (A), Vol. 202, pages 1—69. *The Constitution of the Copper Tin Series of Alloys*, by C. T. Heycock, F.R.S., and F. H. Neville, F.R.S. (Bakerian Lecture).

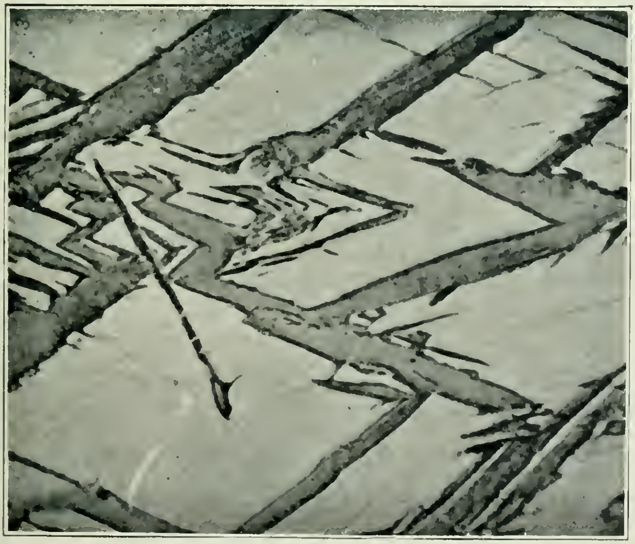
(6). *The Metallographist*, Vols. 1 to 6, published by Sauveur & Whiting. This paper is now issued under the title *The Iron and Steel Metallurgist and Metallographist.*

(7). The *Journal of the Iron and Steel Institute.* This contains many valuable papers in which are embodied the results of recent researches.



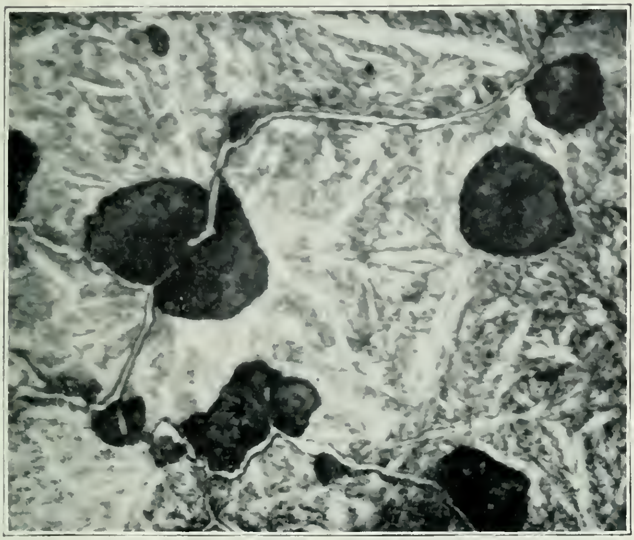
1.—Magnification × 1000.

Cementation Steel. Carbon content 1·60 %.
Polish attack.
PEARLITE and CEMENTITE.



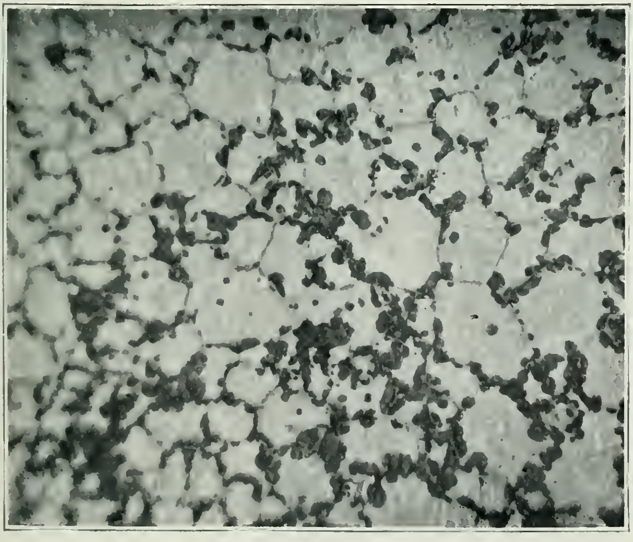
2.—Magnification × 1000.

Steel heated to 1000 C. and quenched in a freezing mixture below 0 C.
Etched 10 solution H.C.L.
AUSTENITE and HARDENITE.



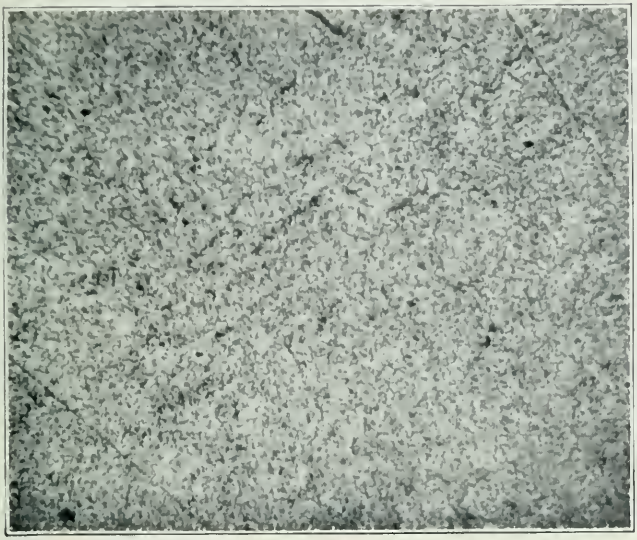
3.—Magnification × 500.

Steel heated to 900 C. and quenched in water. Carbon content ·4 %.
Etched Picric Acid.
MARTENSITE, TROOSTITE, and CEMENTITE veins.



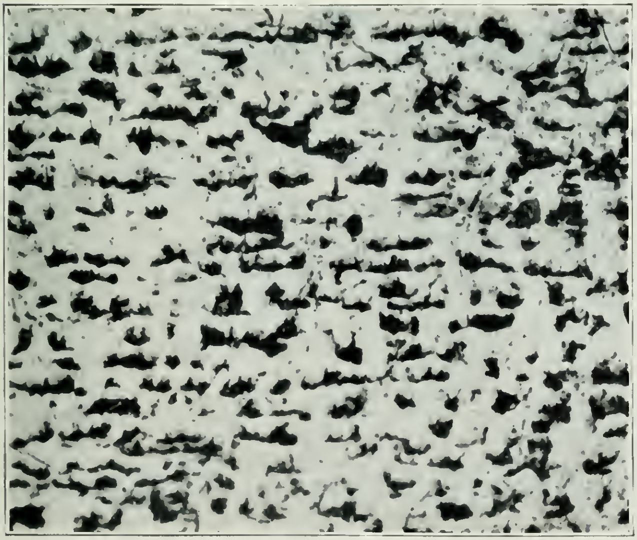
4.—Magnification × 50.

As for No. 3.



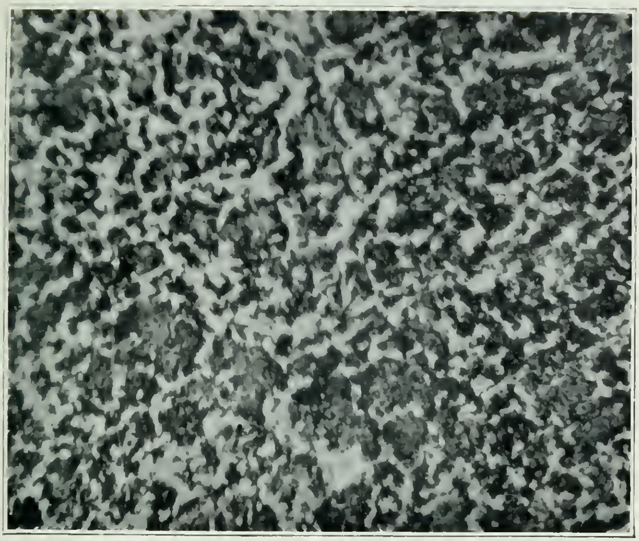
7.—Magnification × 180.

Nickel Steel Armour Plate.
Etched Picric Acid.



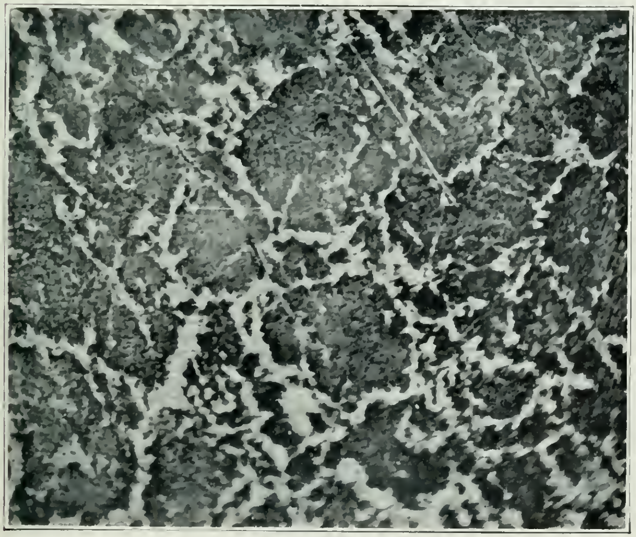
8.—Magnification × 180.

Steel Boiler Plate. Carbon content ·16 %.
Etched Picric Acid.
PEARLITE and FERRITE.



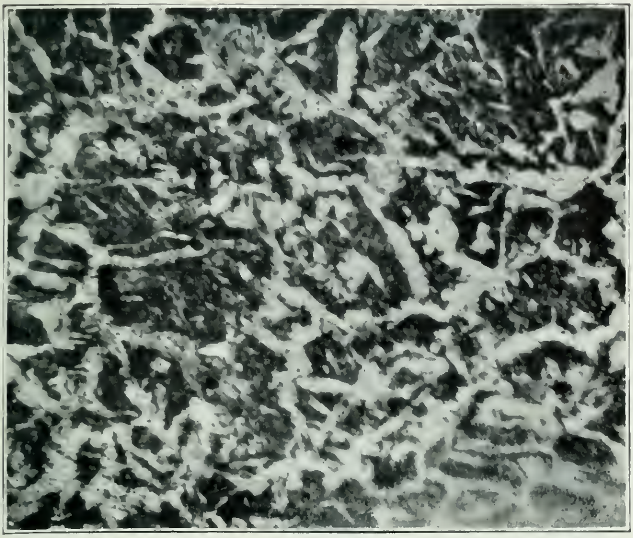
9.—Magnification × 180.

Steel Rail; section from web. Carbon content ·347 .
Etched Picric Acid.
PEARLITE and FERRITE.



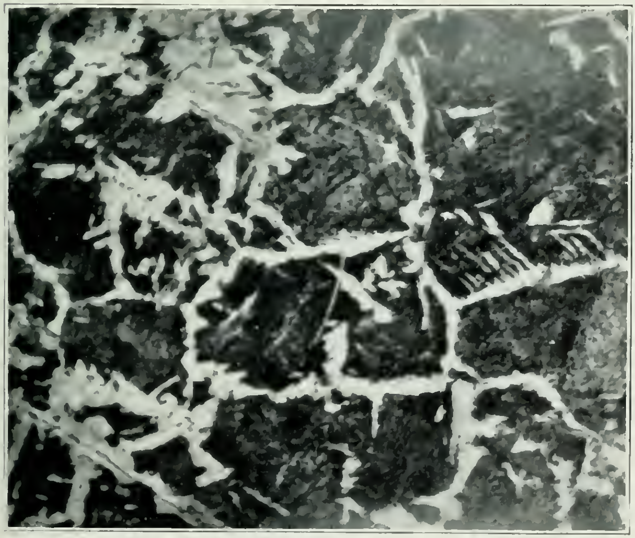
10.—Magnification × 180.

Steel Rail; section from flange.
As for No. 9.



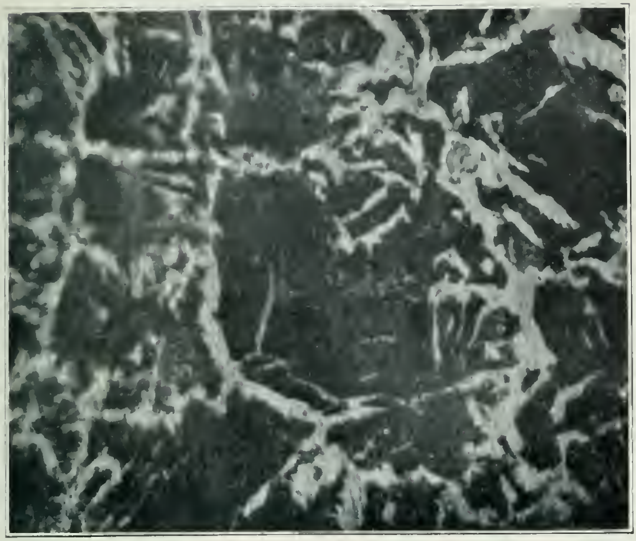
11.—Magnification × 180.

Steel Rail: longitudinal section from upper edge of head.
As for No. 9.



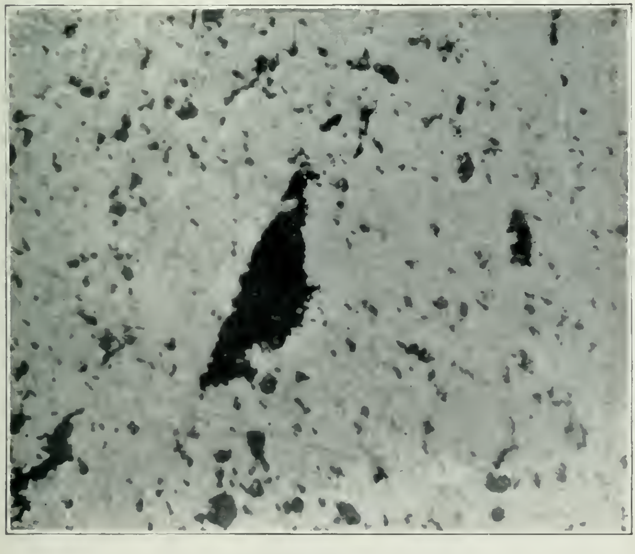
12.—Magnification × 180.

Steel Rail: longitudinal section from centre of head.
As for No. 9.



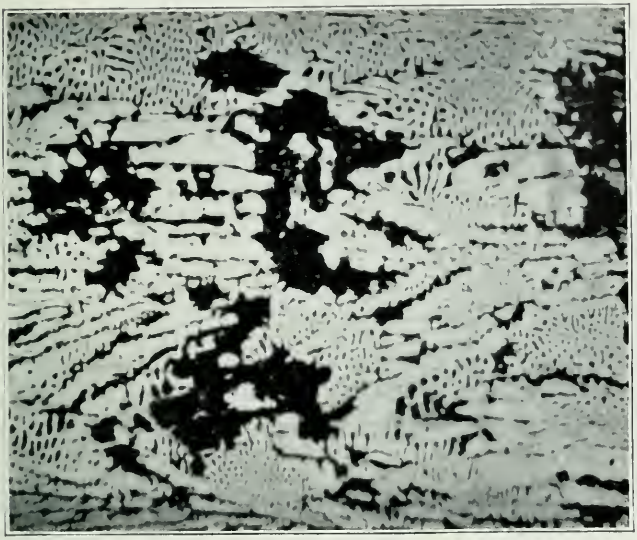
13.—Magnification × 180.

Steel rail: transverse section from centre of head.
As for No. 9.



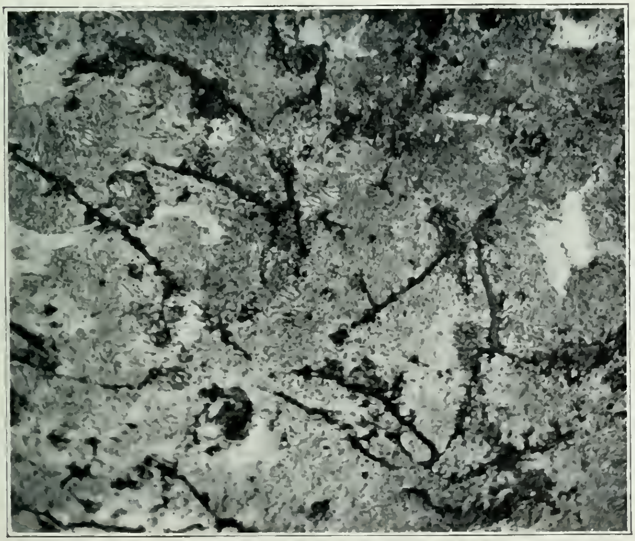
14.—Magnification × 180.

Wrought Iron. FERRITE and SLAG.



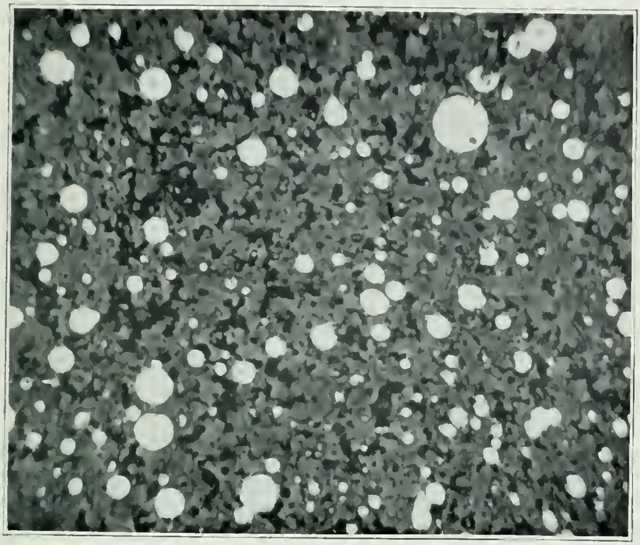
15.—Magnification × 180.

Chilled Cast Iron. Carbon content 4·60 %.
Etched Picric Acid.
PEARLITE and CEMENTITE.



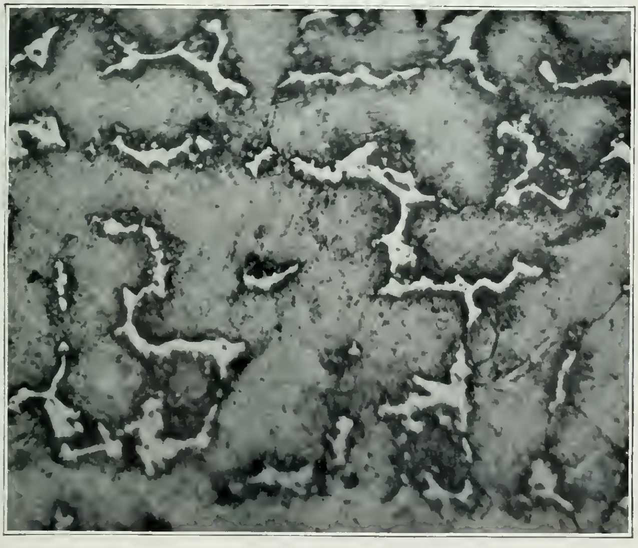
16.—Magnification × 180.

Grey Cast Iron. Carbon content 2·98 %.
Etched Picric Acid.
The chief constituents are GRAPHITE and PEARLITE.



17.—Magnification × 50.

BRONZE containing LEAD.
The white round spots are lead.
Specimen heat treated and pressed on glass.

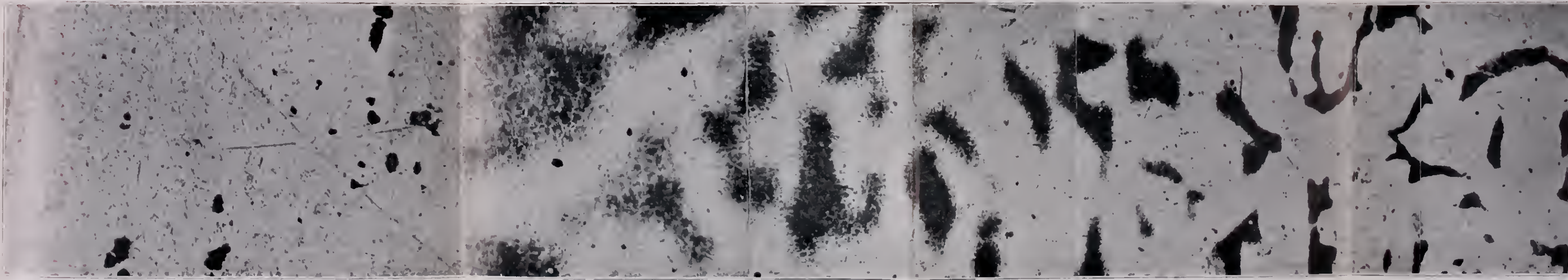


18.—Magnification × 180.

BRONZE.
Cu 81 %. Sn 15 %, with a small proportion of lead and nickel
Etched Fe_2Cl_6.

19.—Magnification × 60.

STEEL containing ·16 CARBON.
Etched Picric Acid.
Specimen subjected to heat treatment at one end.

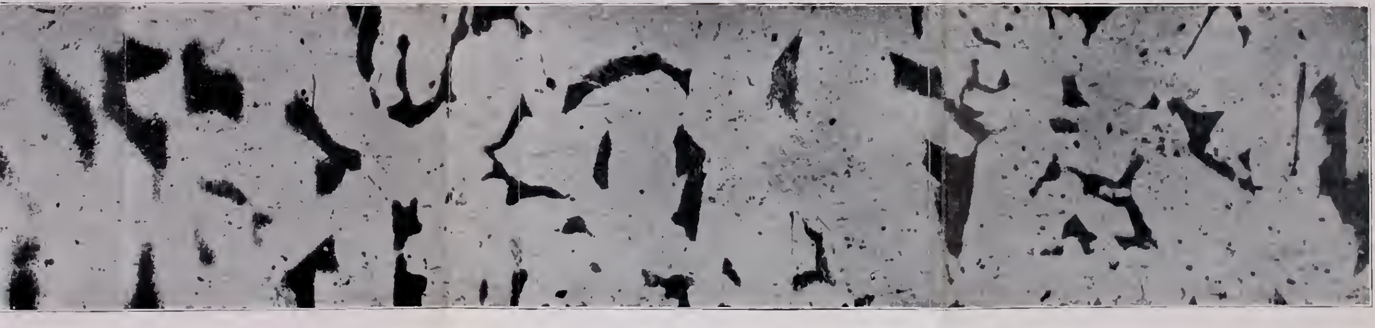


Very finely divided
PEARLITE and FERRITE heated end.

Partially segregated
PEARLITE and FERRITE.

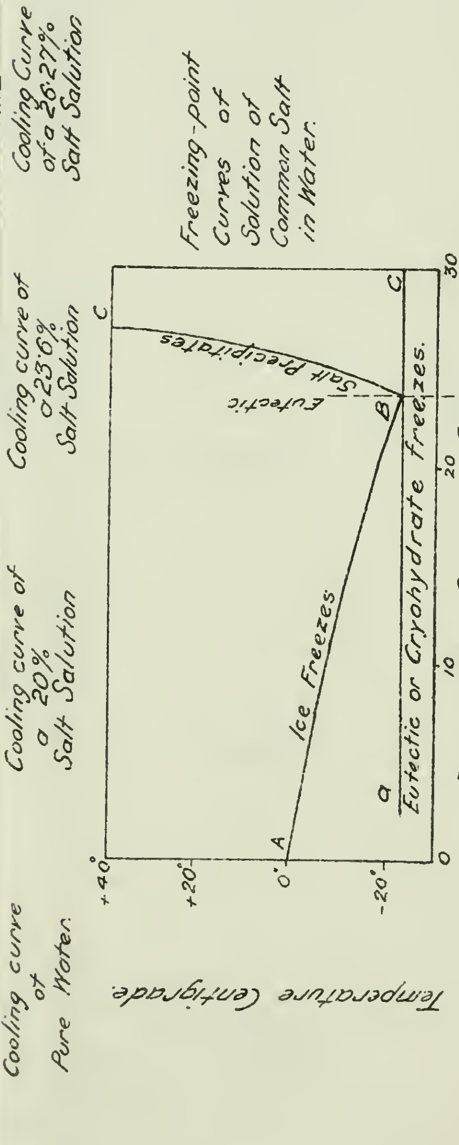
19.—Magnification × *60.*

STEEL containing ·16 CARBON.
Etched Picric Acid.
Specimen subjected to heat treatment at one end.



PEARLITE and FERRITE
Cold end.

URVES OF WATER
LT SOLUTIONS.



PLATE, I

COOLING CURVES OF WATER AND SALT SOLUTIONS.

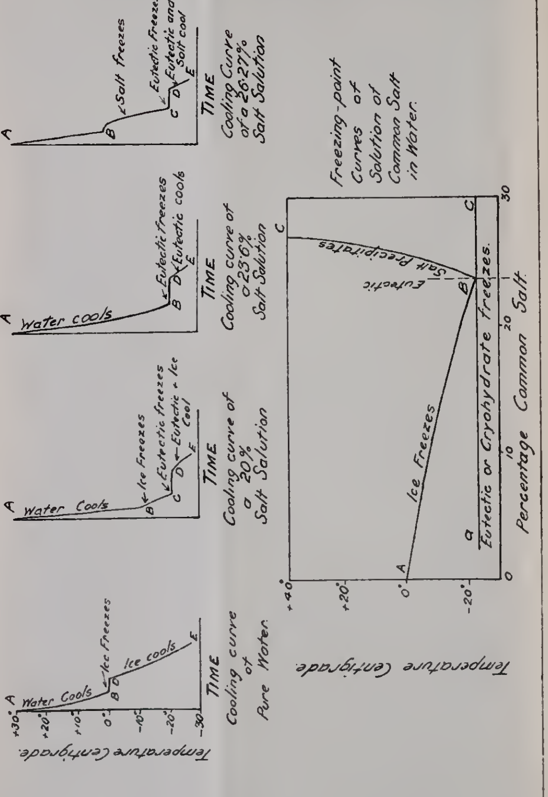
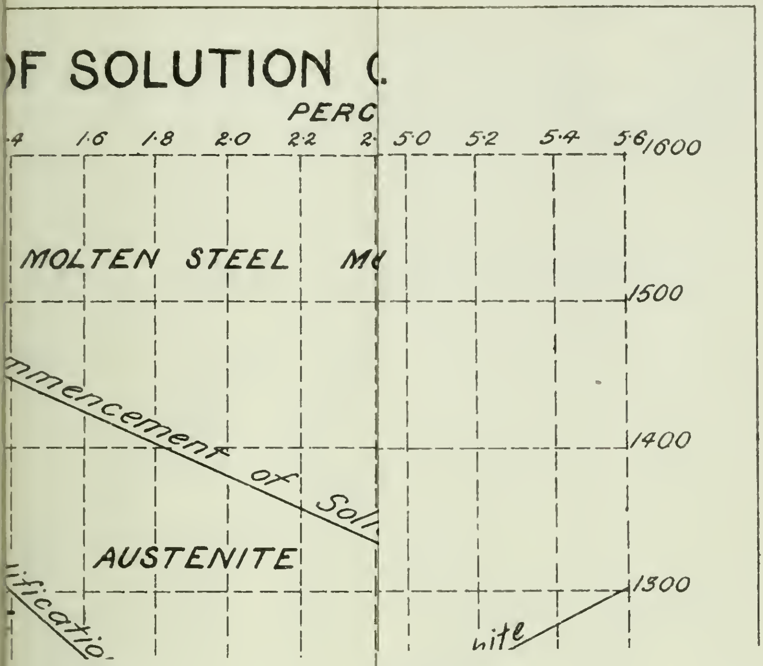


PLATE.II



OF SOLUTION C
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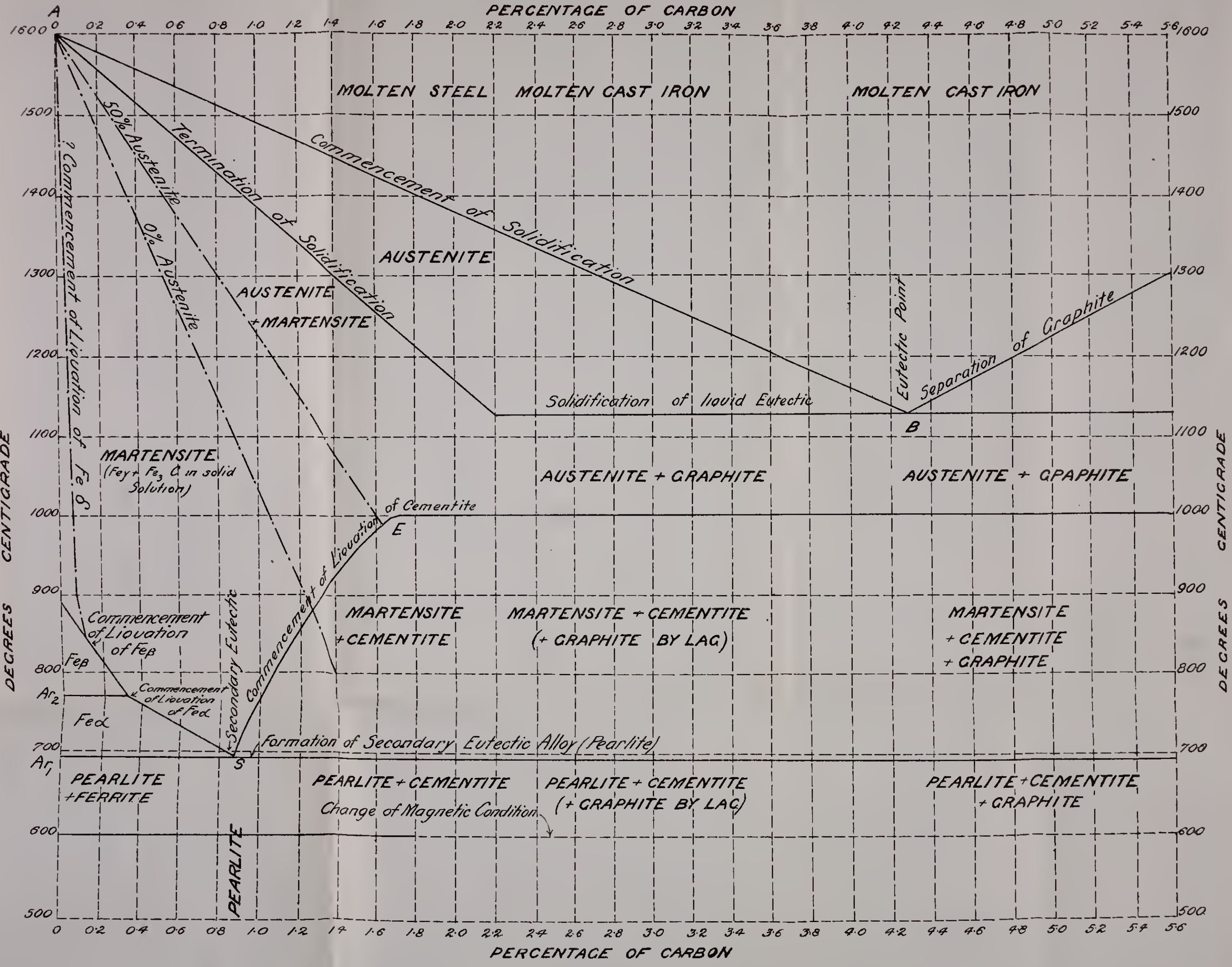
PLATE. II

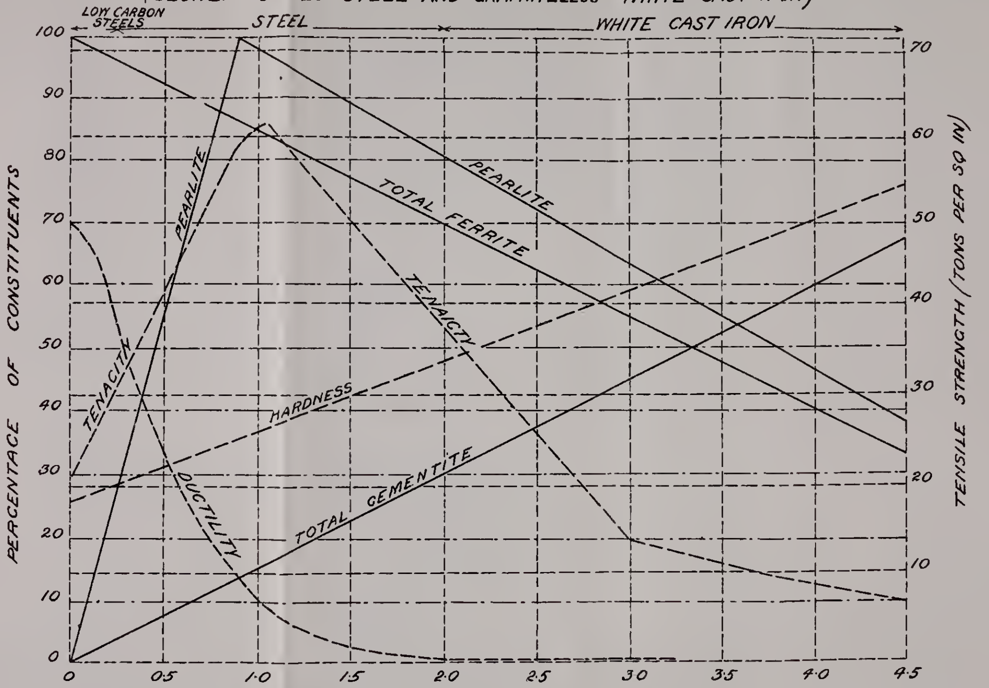
CURVES OF SOLUTION OF PURE IRON CARBON ALLOYS.



PLATE, III

SKETCH DIAGRAM OF
PHYSICAL PROPERTIES AND MICROSCOPIC CONSTITUENTS OF THE PEARLITE SERIES.

(SLOWLY COOLED STEEL AND GRAPHITELESS WHITE CAST IRON)

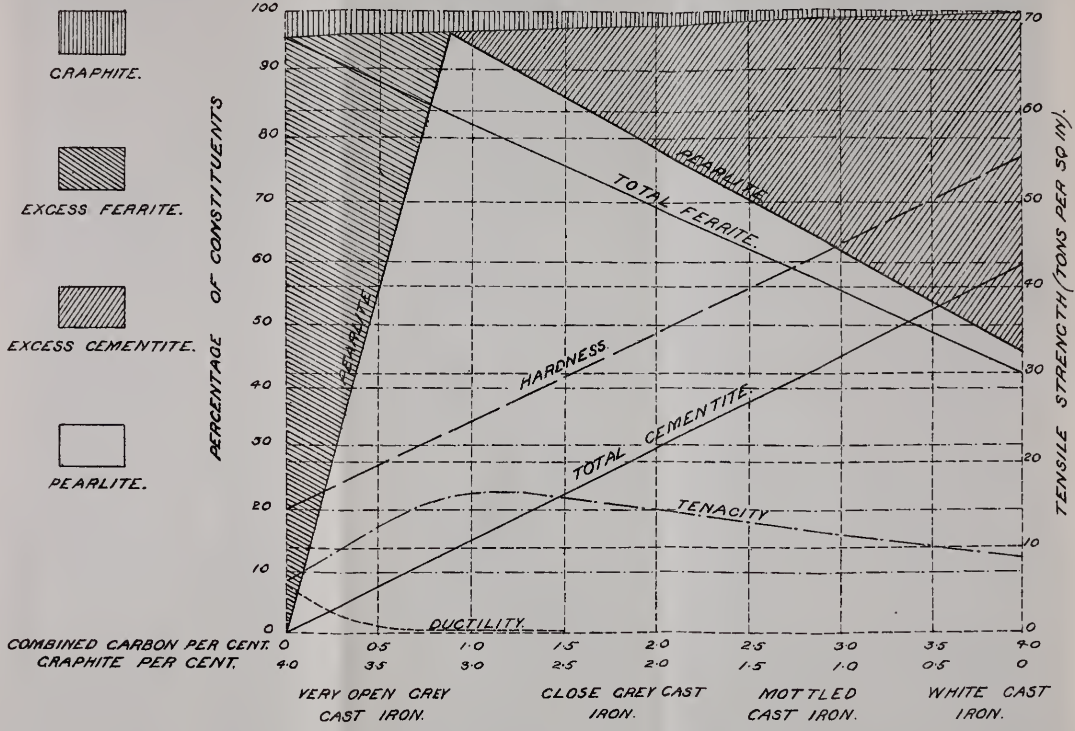


Total Ferrite = Excess Ferrite + the Ferrite in the Pearlite.
Total Cementite = Excess Cementite + the Cementite in the Pearlite.
Tenacity and Ductility = The Tenacity and Ductility curves apply approximately only to ordinary commercial structural steel such as plates, girders, angles etc,

PLATE IV

SKETCH DIAGRAM OF PHYSICAL PROPERTIES AND MICROSCOPICAL CONSTITUENTS OF CAST IRON CONTAINING 4% CARBON.

SHOWING THE EFFECT OF DISTRIBUTION OF THE CARBON BETWEEN THE COMBINED AND GRAPHITE CONDITIONS.



PAPER XI.

PIETER'S HILL: A TACTICAL STUDY.

BY

MAJOR F. A. MOLONY, R.E.

PIETER'S HILL: A TACTICAL STUDY.

THE battle of Pieter's Hill (14th—27th February, 1900) was the best contested of the recent Boer War. It was also the most critical; for on it depended the fate of Ladysmith, which was then at the end of its provisions. It is commonly believed that the fall of Ladysmith was to be the signal for the rising of the Dutch in Cape Colony.

Pieter's Hill was fought on very varied ground. Both sides made large use of defences; and a great deal of bridging had to be done, as the Tugela was in half flood. It is therefore hoped that the following account may be of interest to the Corps.

To appreciate fully the perseverance shown by the Army of Natal during these operations, we must bear in mind that it had already suffered three serious reverses.

Colenso was an attempt to open the direct road from Chieveley to Ladysmith, which runs over the Grobelaar's Kloof range. Spion Kop was an effort to pass round the Boer right by the Trichard's Drift-Acton Holmes road. Vaal Krantz was meant to break through the gap between the Spion Kop and Grobelaar's ranges.

The Pieter's Hill operations resulted in opening up a cart-track alongside the railway.

The position held by the Boers on each side of Colenso is too well known to need detailed description. Their left was on Cingolo, 7 miles east of Colenso (*Plate* I.); their right extended a corresponding distance up the Tugela, and was very strong as their bank dominated ours. The whole position was heavily and skilfully intrenched; it was cut in two by the Tugela, but the Boers had bridged this with railway material at the middle falls.

Hussar Hill, 14th February.

In mid-February the Tugela was in half flood, thus making the Boer centre and right unassailable, but jeopardizing their communications with their left. Therefore, when Lord Roberts instructed Sir Redvers Buller to try once more to relieve Ladysmith, attention was naturally directed to the Boer left. Hussar Hill was seized after a skirmish on the 14th, and this was the commencement of 14 days' continuous fighting.

Cingolo, 17th February.

A glance at *Plate* I. will show how salient was the Cingolo position. Presumably the Boers trusted to its height and roughness; but these qualities assist an attack, though they render it slower.

The 15th and 16th were too hot for infantry movements, but on the 17th February Cingolo was assaulted by 1 mounted and 3 Infantry Brigades under General Lyttelton, and taken after a sharp fight. A sufficient force was employed, and a converging attack was made over ground which favoured the preponderating arm, the infantry; hence our success.

Monte Christo, 18th February.

This, however, only brought us in front of the Boer main position, which was on Monte Cristo. The nek between it and Cingolo was well entrenched, and a kraal aided the defence.

But we had now got a considerable amount of artillery into position, one battery being high on Cingolo mountain; and Monte Cristo was assaulted and taken early on the 18th. (The British positions at this crisis are shewn on *Plate* I.).

The reasons for this success appear to have been :—

1st. The skill and speed with which the attack was carried out.

2nd. Botha thought the whole movement against his left a feint, and hence did not reinforce it in time. His reinforcements had to go round by the temporary bridge, and so arrived too late.

3rd. The terrain was not favourable to the tactics of the Boers, who like to fight near their horses. Those on the extreme left had to leave their ponies the other side of Monte Cristo.

4th. The superiority of the British artillery, and the hard work done by the Devon and West Yorks regiments in getting some of the guns to a commanding position at night.

The whole Boer position south of the Tugela was rendered untenable by our capture of Monte Cristo. Had they possessed an artillery capable of coping with ours, and prepared suitable defences, they might have thrown back their left with Hlangwani at the angle.

The men holding Hlangwani would have been in no worse case than the Devons at Ladysmith; this regiment, by means of heavy intrenchments, defended a salient hill, on which the Boers were able to fire from an arc which was considerably greater than a semicircle, and which was much more commanded from Bulwana, Gun Hill and Pepworth than Hlangwani was from Monte Cristo.

Hlangwani, 19th February.

No intrenchments, however, had been made on Hlangwani facing east; and on the 19th it was shelled by our guns and captured after a skirmish, during which the curious situation arose of our men on the east side of the hill and the Boers on the west side being both enfiladed by hostile artillery fire.

Close under Hlangwani, the Tugela makes a bight, ¾ of a mile across and the same in depth, before the slopes of Fort Wylie begin. The centre of this bight is bare veldt, and the banks not sufficiently wooded for sharpshooters to get about unseen. Hence the Boers could not dispute the construction of a pontoon bridge under Hlangwani, and a passage of the Tugela was thus secured.

The crossing of an unfordable river is a much more difficult operation than text-books represent, as men rowing across in boats or pontoons afford a very vulnerable target to small posts on the further bank. The increased range of rifles has greatly reduced the number of such posts necessary, and hence an army can occupy a great length of river line and still keep large reserves to reinforce a threatened point.

Smokeless powder makes it impossible for the assailants to immediately discover the situations of the defenders' posts. Hence, if the latter reserve their fire until the boats are in the water, they should be able to render any number unmanageable before they can be rowed across.

These facts must be continually borne in mind when considering the operations on the Tugela; they alone explain General Buller's action in crossing the river at a point where his fire from the nearer bank could drive all defenders from the further side.

It is generally urged that Buller's movement should have been continued north *viâ* Monte Cristo, which height he ascended on the 20th to reconnoitre a route for his further advance. North of this mountain the Tugela flows in a profound gorge, and the critics probably mean that the passage should have been made north-east of Monte Cristo, though this plan is not accurately defined.

But there were some strong reasons against this. It was giving up a certainty of crossing for a probability. There were no proper maps of the country, and it did not seem likely that so favourable a point for forcing a crossing could be found; it was also unlikely that infantry and pontoons would forestall mounted Boers. Again, this route would take the army a long way from its line of communications;

and when it was east of Monte Cristo, the Boers might attack Chieveley, for they knew every drift and ford of the river. A railway is a very convenient line of communication, but it is a very vulnerable one; and this was felt so much that General Burn-Murdoch's Cavalry Brigade was employed to guard our left flank till almost the end of the operations.

Again, east of Monte Cristo there was no known road down to the Tugela, or up the other bank; and, from the view obtainable of Asvogel Kop from Monte Cristo, it looked as if a position facing east could be taken up on the eastern slope of the former range, which could not be enfiladed from the latter.

Added to these considerations was the fact that the whole of the immense Boer laagers between Buller's army and Ladysmith had been removed, and that large numbers of Boers, waggons, carts, etc., had been seen from Monte Cristo streaming over the flat between Kitchener's Hill and Pieter's Station; whilst Lord Roberts and General White reported the Boers moving west and north from the Tugela. It was believed these signs meant a general retreat of the Boer army, but the movements were more probably the withdrawal of the Free Staters, who had now heard of Lord Roberts' concentration at Ramdam and were alarmed for their own capital.

Their withdrawal was hard on Botha, and fatal to their cause. Serious operations were in progress on the Tugela, and they should have stayed at least until the next definite pause in the fighting. They were moving across the whole breadth of the Orange Free State during the most critical period of the war, and were too late to save Cronje at Paardeberg.

The Boer position on the Tugela.

In spite of their withdrawal, Botha determined to check Buller's advance by taking up a position cutting off the whole river bend dominated by the Hlangwani plateau. To minimise the effect of our powerful artillery he endeavoured to site his trenches either on hills higher than the Hlangwani plateau, or on ground difficult for our guns to search. His position had to start from the loop in the Tugela (4 miles west of Hlangwani, see *Plate* I.), where Hart's Brigade got caught at the battle of Colenso; and thence ran for 5 miles in a north-easterly direction to the knoll, east of the railway, where Lieut. Daly's monument now stands (see *Plate* II.).

The left of the position did not exactly rest on the Tugela, but the Boers had a double safeguard against their left being turned. No British could cross the Langverwacht spruit by day without coming under rifle fire at under a mile range, nor the spruit under Kitchener's Hill without coming under fire at 900 yards range. It is true that the assailants could cross these spruits by night; but, as the whole country is strewn with boulders, movements at night were very difficult, and Botha probably thought it unlikely that we should fight with the flooded river running close in our rear for 3 miles.

The fact we should specially notice about this position is that the Boer trenches were traced on every sort of slope. On the left flank, where the hills were high and our artillery positions distant, they occupied the forward crest, just as we should have done. On Hart's Hill they were on the highest summits. On Hedge Hill they were fairly on the back slopes, firing up-hill. Green Hill is an almost level plateau; the Boer trenches were at its rear edge. On the next hill they were a little more forward. They then ran along the bank of the Onverwacht spruit, on the side nearest our advance, where they had a good field of fire over nearly flat veldt. In the centre their field of fire in front was often very limited; but the position being straight, the Boers generally got a cross fire on the front of each hill. Thus no one could ascend Hart's Hill without being under fire either from Kitchener's or from Hedge Hill, though the trenches on the latter were far retired.

The position chosen everywhere fulfilled what was a vital condition to the Boers,—they could get up to the trenches from their immediate rear under cover, and could therefore keep their ponies close up.

Otherwise the lateral communications were not very good, as several ravines cut up the ground, and the Boers could not cross the Langverwacht spruit unseen.

On Hedge Hill and Green Hill, where our artillery was most to be feared, the Boer trenches were so placed as to be extremely difficult to hit. They were often only visible from one direction,—if a somewhat unusual accumulation of rocks, barely visible through a good telescope, can be called visibility. On the west slope of Hart's Hill the trench was sited so as to be just out of view from the Hlangwani plateau; the parapet all across this hill was very strong, being generally 4 feet high and thick, with a trench behind about 3 feet deep and broad. On this stony ground it was far easier to collect boulders than to excavate a trench, but by means of large gangs of Kaffirs a great deal of trench digging was accomplished.

In one case on Kitchener's Hill a trench with no parapet was placed in continuation of a parapet with no trench. The latter was probably meant to draw our fire, while the Boers lay in the former; and from the former they could crawl to the latter when the closeness of our infantry attack should compel us to cease firing and more command became desirable. This type seems well worth imitating.

The enemy's main artillery position was $1\frac{3}{4}$ miles behind their centre, on a hill higher than Hlangwani and nearly as high as Monte Cristo, from which the guns were hidden by a high knoll. Boer "slimness" was carried too far in this matter, as the same knoll afterwards prevented the guns being turned on our attack; moreover Monte Cristo was 9,000 yards away, and experience at Ladysmith should have taught the Boers that a gun is very unlikely to be disabled at even half that range, for during the whole of that siege a 6·3-inch howitzer of ours was the only piece directly hit. The Boer emplacements were well constructed, one having a parapet 5 feet high and 10 thick. In two cases the guns were served behind a natural bank of rock. There were four other gun emplacements on this hill.

There were also several Boer guns and pompoms on the Grobelaar's Kloof range. Also a howitzer and two pompoms between the main artillery position and Sheba's Breasts; and a gun near Pieter's Hill.

The Boers would have been better advised to bring forward the whole of their heavy artillery from the attack of Ladysmith. Their general bombardment of the town and camps was doing no good, and it was too late to begin siege operations; whilst the garrison were now too much exhausted by their privations to attempt any sortie on a large scale. Everything turned on the blockade, and a few pompoms would have sufficed to prevent the defenders enlarging their grazing ground.

But even with the guns on the spot, the Boers would have done better to place their main artillery position between Sheba's Breasts and Pieter's Hill. This might have enabled the burghers to hold their ground by means of good trenches on Hedge Hill, Hart's Siding Hill and Terrace Hill, and would have greatly decreased the total length of their position.

Anxiety to avoid loss drove Botha to an undue extension of his line; but in spite of the withdrawal of the Free Staters, the Boers were confident that they could hold the position.

On our part we knew nothing about the Boer plans. The ground had never been mapped. The trenches were practically invisible, and those on Hedge and Green Hills were hardly suspected, owing to our rigid ideas as to posting troops on the forward crest. It appeared that, if the Boers resisted at all, it would be on the slopes of Grobelaar's Kloof and on the line of heights connecting it with Pieter's Hill.

On the Boer centre and right of this supposed position, no defences whatever were visible, except some forming part of the old Tugela line. Hence our chiefs were confirmed in the idea that serious resistance was at an end.

19th and 20th February.

Precautions, however, were not omitted. The 19th and 20th were spent in driving the Boer rearguard off the Hlangwani plateau; in road-making, and getting up guns to that plateau, and in reconnoitring from it. The howitzers were brought on to Monte Cristo, and the West Yorks' maxim posted at the extreme north end of that height, to try and keep the enemy off Asvogel Kop. Hildyard's Brigade reinforced Barton's on Hlangwani, on the northern spur of which was built an emplacement for the Naval 4·7-inch guns. The Boers annoyed our men by pompom and rifle fire from across the river; but our bank was cleared of them on the 20th and two large laagers, which had been hidden behind Monte Cristo and Hlangwani, were captured, with 1,700 new picks and shovels and a quantity of ammunition.

On the night of the 19th, the large Boer search-light on Grobelaar's was freely used to watch our movements till stopped by the Naval guns. The Rifle Reserve Battalion, supported by the Royal Lancasters, drove a few Boers out of Colenso before dawn on the 20th, but Hart's Brigade then came up and Colenso was left to him.

Thorneycroft's Mounted Infantry forded the Tugela by the well-known drift just below the road-bridge and occupied some of the nearer kopjes, and Fort Wylie was found to have been abandoned by the Boers. Trains were run up to Colenso.

Tugela Crossed, 21st February.

On the 21st the first pontoon bridge was constructed west of Hlangwani, and the 5th (Warren's) Division began to cross it. The 10th (Coke's) Brigade led, with orders to reconnoitre the kopjes north and west of Fort Wylie and then advance to Onverwacht spruit, the upper ravine of which was to be searched with artillery fire. Another large laager with a quantity of ammunition was captured behind Fort Wylie, and the howitzer battery was brought into action there, but the range was too great and it was soon moved forward.

At 1 p.m. the advance was continued in a north-westerly direction; but, as already explained, the proximity of the Boer main position was not suspected and the Somerset Light Infantry, which were covering the right flank of the battery firing up the Onverwacht ravine, came suddenly under a heavy fire in the re-entering bend of that spruit. The other battalions supported well, and for 5 hours the engagement was carried on at short ranges. The Somersets could not be withdrawn till dark, and lost heavily.

It is impossible for those who have not been under fire from smokeless powder to realize how difficult it is to locate an enemy's position. Zeiss glasses may be diligently used for half an hour without discovering where the fire is coming from. The Boers would often let the scouts walk up to their trenches without firing at them, waiting for a better target. Theoretically scouts should be half a mile ahead, but it is very difficult to get men to do the work properly, and if officers are habitually employed at it a battalion will soon have none left. Our men are unaccustomed to face danger alone, and the same eerie feeling of loneliness comes over them as over the young sportsman when he gets on ground where he believes no white man has ever been before. When the scouts approach cover which they fancy conceals a foe, they hesitate, and begin signalling to each other. Then, to avoid further delay the officer goes forward to get them on, his skirmish line follows, and the whole get close to the enemy before fire opens. The Boers were adepts at holding their fire, and at preventing their dispositions becoming known; no traitor revealed their plans, and no spy could find out anything.

Advance on Green Hill, 22nd February.

The night of the 21st was wet. Before daybreak on 22nd the 2nd (Hildyard's) Brigade crossed the river by the pontoon bridge, and successively occupied the nest of low kopjes to the right of Coke's Brigade. The artillery on the left bank of the Tugela were brought up to 4 field and 1 howitzer batteries and 2 Naval 4·7-inch guns; all these were posted facing north near the west end of the bridge. The 5th (Hart's) Brigade came up from Colenso. A great deal of transport was also brought over the river, and drew the Boer artillery fire.

About noon the 11th (Wynne's) Brigade advanced on Green Hill and Pompom Ridge which had been well shelled, and the firing became rapid on both sides. The South Lancashires and Royal Lancasters led, supported by the King's Royal Rifles and the Rifle Brigade of the 4th (Norcott's) Brigade. Considerable loss was incurred in passing Onverwacht spruit, but Pompom Ridge, the nearer half of Green Hill and the near end of Hedge Hill were successively occupied. The Boers could be seen working at their entrenchments on Hart's Hill. General Wynne was wounded at 2 p.m. and his brigade was taken over, first by Colonel Crofton and then by Colonel Walter Kitchener.

Many accounts represent General Buller as having brought over almost all his artillery on this day. This is hardly correct. There were still 4 5-inch guns, 6 Naval 12-prs. and a mountain battery on the Hlangwani plateau, besides 2 field batteries which were placed on some low hills between this plateau and the confluence of the Onverwacht spruit with the Tugela.

It was certainly wise to leave a strong force of artillery on the right bank. If the Boers were fighting a rear-guard action, a few field guns would be sufficient with the column pushing for Ladysmith; if they were going to make a firm stand, the bulk of the guns could be best employed on the right bank. The only question is whether the 2 4·7-inch guns and the howitzers should have been brought across; but it was certainly desirable to employ some long range guns on the left flank; and the range of the howitzers being comparatively short, it was thought best for them to follow the advance closely.

It is more difficult to defend the bringing over of the transport. Too great a force was getting massed north of Fort Wylie, and it suffered from the Boer fire accordingly.

General Buller felt this, and when Burn-Murdoch's Cavalry Brigade began to cross the bridge he ordered them back. It had come up from Springfield, where it had been guarding the extreme left and so protecting the railway from Boer enterprises, which were now improbable as their front was so closely threatened. Also Sir G. White had reported that the enemy near Spion Kop had fallen back.

The number of little crescent-shaped sungars, which still exist on the reverse slopes of all the hills occupied by our troops at this time, bear eloquent testimony to the accuracy of the Boer fire. Three Boer shrapnel alone put 19 men and several animals *hors de combat,* and these were sheltering behind a steep slope!

On this day (the 22nd) Colonel Bethune, with a detached force, began an advance from Tugela drift against the extreme Boer left flank.

In the evening Hildyard and Kitchener tried to advance their outposts to the far end of Green Hill, unaware that the Boers held it in force. One company of the King's Royal Rifles drove the Boer outposts to the back of the hill, but they were unsupported; and when the Boers opened a heavy fire from the main trench they had to lie where they were.

Night Engagement on Green Hill and Pompom Ridge.

A general, confused, and altogether indescribable night engagement then took place on Green Hill and Pompom Ridge. Charges and counter charges were made on the latter, and some Boers were bayoneted.

At early dawn on the 23rd the company of the King's Royal Rifles, realizing that they were in too forward and isolated a position, began to dribble back. A company of the East Surrey came forward to support them and both lost heavily. The enemy's fire, which had not ceased all night, became very hot at daybreak. On Green Hill, some men retired from an advanced sungar, but the Devons dashed forward and re-occupied it, coming in for an accurate shell fire from a 3-inch Creusot. Slightly behind them the maxim of the West Yorks was brought into action against the west slope of Hart's Hill. Indeed every gun and almost every rifle was in full use, and it is impossible to discover or chronicle their targets.

Terrace Hill and Hart's Hill, 23rd February.

The great move of the day was now to be made. From Buller's position on a rough rocky kopje a little N.W. of the pontoon bridge, it appeared that the triangular eminence now known as Hart's Hill was the key of the Boer position. A general attack to the north-west might result in the capture of Green Hill and Pompom Ridge; but the Boers, if driven from these, could take a new and dominating position on Grobelaar's and on the hill occupied by the bulk of their artillery. The capture of Hart's Hill looked as though it would render this second position untenable, and the approach to Hart's Hill *viá* the river and Terrace Hill seemed fairly covered. General Hart was directed to work along the river bank, but not to attack the hill which now bears his name unless he saw a good prospect of capturing it without heavy loss. The hill was heavily bombarded, the 6 howitzers firing 374 rounds on this day.

About 11 a.m. the brigade moved over Howitzer Ridge in too close formation, and drew a heavy and telling fire. It then went into column of route, and followed the river bank closely; but in crossing the two spruits exposure could not be avoided. The Royal Engineers had begun to erect a sandbag parapet along the bridge over Onverwacht spruit. The river was so full that it backed up the Langverwacht spruit for 100 yards, and the men had to double across the railway bridge under so heavy a fire that many fell. The nearest pompom was a mile away, but the Boers held sungars nearer than this; and these enfiladed the spruit, so that our men would have lost equally if they had not used the bridge. The brigade moved another mile down the river bank, and then turned to the left and worked up Terrace Hill.

Our fire from the north of the Hlangwani plateau had cleared the Boers from this last-named spur, and the railway was reached without severe loss; but the Inniskilling Fusiliers on the right now came under fire from Kitchener's Hill and the Connaught Rangers on the left from Hedge Hill. Nevertheless the brigade pressed up the slope of Hart's Hill, and drove the Boers back from their advanced sungars on the forward crest. The Inniskillings, having less slope to climb, gained the top first.

But we had only taken one angle of the triangular plateau; the Boer trenches on the other angles were on slight knolls. The top of this hill is very deceptive; the scattered trees are the same shape as the bushes near the river, but double the height; this makes the top look scarcely more than 100 yards across, whereas it is over 300, and this 300 yards is covered with hidden boulders very difficult to charge over. As the knolls appeared to be within charging distance and the day was nearly over, a charge was ordered, though only 2 battalions were up. The Inniskillings dashed forward, and were met by a terrific magazine fire, not only from the knolls but from a hitherto unsuspected trench extended between them. Thus the defenders were on a wider front than the assailants, and the charge had no chance of success. In spite of grievous loss the charge was renewed by the Connaught Rangers and Dublin Fusiliers, and at least one man reached the Boer trench; but the lines were mown down by the withering fire, and the few survivors ran back to cover. The Boers moved forward on the right of the Brigade, but as long as daylight lasted our powerful artillery from the far side of the river held them in check. Some of our men clung to the angle of the hill, where they built parallel sungars, back to back, to gain a little cover from the cross fire; the majority, however, had to retire to the railway cutting and the slopes of Terrace Hill, where they built heavy stone sungars.

Though the assault on Hart's Hill had failed, the great advantage had been gained of a footing on Terrace Hill, which, however, was only retained by the splendid tenacity of the Irish Brigade. The Boers made repeated small counter-attacks during the night, but could not drive our men back.

Movements on 24th February.

Meanwhile the Royal Engineers built a sandbag parapet on Pompom Bridge, and early on the 24th the West Yorks and East Surrey moved over it to reinforce Hart's Brigade. The Boers had lost a great opportunity. Had they made a general counter-attack on Hart during the night of the 23rd, moving by both flanks of

Hart's Hill, they could hardly have failed to drive his men back into the river, considering the very heavy loss the Brigade had suffered. But the Boer lack of discipline prevented their making general counter-attacks, and so the dangerous time passed without mishap.

On the 24th General Warren was sent forward to order Hart to renew his attack; but fortunately both these Generals concurred in thinking that there was no chance of success for such a local effort on a necessarily narrow front, and Warren procured Buller's acquiescence in this opinion.

Affairs, however, had arrived at a deadlock. Hart was evidently not on the left flank of the Boers, and already our right was fighting on a front of a mile and a-half with a flooded river half a mile in their rear. It was evidently dangerous under existing conditions to make the right flank reach out further for the enemy's left. It was almost as dangerous to make a general assault on their left, as if any disaster happened there our whole right might be cut off. It was even feared that a general retirement would be ordered.

Fortunately bridging operations had been pushed on at Colenso; planks had been slung around and between the old piers at the broken railway bridge, and a pont rigged above the road bridge. Therefore the pontoon bridge could be dispensed with for a time. Colonel Sandbach, R.E., found a valley leading from the Hlangwani plateau to the river behind Hart's position; and a road was ordered to be constructed, so that the pontoons could be got down.

Arrangements were also made to mass the bulk of the artillery on the northern slopes of Hlangwani, emplacements being formed for the most exposed guns. Another attempt was to be made to get round the Boer left flank.

Meanwhile a terrible misunderstanding had arisen on Hart's Hill. A few of our wounded lying there had been attended to by the Medical Officers during the night; but on a lantern being unfortunately shown, the Boers opened a heavy fire, which they resumed at intervals all night. In the early morning of the 24th some Boers came out with a white flag, and gave some water to the wounded. This should have been met by a similar party on our side, but there had been so many "incidents" that no one liked to take the responsibility.

Presently some of the Boers began robbing the wounded, and this action so enraged our men that they opened fire. The Boers retreated to their trenches, and a very embittered fire was kept up for the rest of the day. The artillery also fired heavily, the howitzers alone getting rid of 268 rounds. The Boers fired heavily from Grobelaar's on this day; but no important movements of the opposing firing lines took place, except that some of the Irish Brigade crept a little further forward on Hart's Hill. Later in the day this brigade was relieved by Norcott's to enable it to get rest.

More important movements took place in rear. The garrison of Frere was withdrawn, and that of Chieveley reduced. The transport was moved from the left bank of the river to the right, and this was noticed by the Boers, who shelled it heavily.

Partial Armistice, 25th February.

On Sunday the 25th General Buller asked for an armistice to attend to the wounded on Hart's Hill, whose sufferings were terrible to contemplate. The Boers refused a regular armistice, but agreed not to fire on our ambulance and burial parties. This was an advantage to us as it did not prevent the important movements continuing, whilst the Boers, getting up from their trenches to stretch their legs, revealed many hitherto unsuspected works.

Dundonald's cavalry, the 4·7-inch guns, the howitzers, and all the field batteries except the 73rd were sent up to the Hlangwani plateau; two 4·7-inch guns were also placed on pedestal mountings which had just arrived. Four Naval 12-prs. were moved across to Monte Cristo. General Sir C. Warren was put in command of the 4 brigades north of the Tugela. Some of the infantry and almost the whole of the transport were moved back across the river; much to the disgust of the men, who thought that a general retirement was to take place.

At 9 p.m. on the 25th, the Boers made an attack near Onverwacht spruit, but by midnight it was beaten back.

Movements on 26th February.

Early on the 26th these movements were complete, and on this evening the pontoon bridge was taken up and moved round. The artillery were placed as shewn on *Plate* II., and these positions are worth studying as a model. The bulk was massed opposite the part of the hostile position to be assaulted, and was disposed in several lines, so as to avoid the guns being dangerously close together. On the extreme flanks were guns whose long range would enable them to cross their fire on the enemy's centre, and get at the back of the hills on which the Boers had taken position. On the left flank these guns were not actually as close up as was intended, as some Naval 12-prs. from Chieveley, which should have come into action at Colenso, went up to the Hlangwani plateau by mistake. The 6-inch railway gun remained at Chieveley. The 5-inch howitzers were on the nearest ground from which they could fire under cover on the Boer position, the steep angle of descent of their shells enabling them to get searching effect without being far to a flank.

All the visible hills in the Boer position were given names on a rough map supplied to each battery, and the 26th was spent by our artillery in finding the exact range of all these hills, so that fire could be concentrated on any particular one by signal. Thus the advantages of concentration of fire were obtained although the batteries were dispersed; and also great searching effect on the reverse slopes of the Boer hills.

On the 26th the Border Regiment came up with the Rifle Reserve Battalion and Dundonald's Cavalry Brigade; they were told off to line the south bank of the Tugela. The next day they kept up long range fire on the Boer trenches; this helped to keep the Boers under cover, and so reduced our losses.

On this day the Boers seem to have suspected that an attack on their left was intended. They therefore prolonged it about a mile to the north by sungars along the ridge of Pieter's Hill. Consequently their position made a slight angle where Lieut. Daly's monument now stands. But they had no time to dig trenches, nor could they collect enough men to hold their left strongly. The short view from the trenches in their centre now told against them. They had to keep these trenches manned as they might be rushed at any moment.

Many accounts of the battle describe Hart's Brigade as having become the left of our line, but this is scarcely correct. Hart's was certainly the left of the actual assaulting force; but there were, still further to our left and close in front of the Boer trenches, 8 battalions which acted as a containing force and prevented the Boers reinforcing their left from their right.

Tugela Crossed on 27th February.

On the night of the 26th the pontoons were got down to the river, and a bridge constructed below the middle falls. The troops began passing early on the 27th. The bridge itself was covered by the folds of the ground, but the Boers could see the troops marching down to it. Our powerful artillery, however, kept up such a heavy fire that the Boers mostly kept their heads below the parapets.

Pieter's Hill, 27th February.

Barton's brigade crossed the bridge first, and then turned sharp right and worked down the left bank of the river past the lower falls. The West Yorks covered this movement by seizing a hill 600 yards N.W. of these falls, and the remainder of Kitchener's (formerly Wynne's) Brigade formed up on their left. The York and Lancaster arrived from Springfield in time to form a reserve for this Brigade. Norcott's Brigade relieved Hart's front line opposite Hart's Hill.

The men had been encouraged by a message from the Queen, and by the news of Cronje's surrender. It was the anniversary of Majuba. A finger-post at the bridge, marked "To Ladysmith," expressed the idea in everyone's mind. Never did British troops go forward in a more resolute mood.

The assault on Pieter's Hill was to be made by brigades in echelon—right leading. Barton's men had a long way to go over very rough ground, and it was near 11 before they left the river and began the steep climb to the Boer position. They had to cross a valley in full view of and only 900 yards from the Boer trenches, but so heavy a fire was kept on these that only 1 man of Barton's was wounded. Some inconvenience was caused owing to it being impossible for Sir C. Warren to see Barton's attack, and messages as to the latter's progress had to pass through the signal stations south of the river.

About midday Barton's men began collecting at the furthest available cover. Fortunately this was under 300 yards from the Boer trenches; and, unlike Hart's Hill, the attack was here on a wider front than the defence. Taking advantage of the cover afforded by every rock and bush, the Irish Fusiliers worked forward under cover of a tremendous artillery fire, which was kept up to the last moment possible. Then with a dash the trench was captured where Lieut. Daly's monument now stands; fortunately this is a ridged hill, and the bulk of the successful assailants were able to get some cover from the fire poured on to them from the left. Another short rush captured the next knoll. The highest point of Pieter's Hill is a hogback running from the monument north and south-east; consequently it did not present a good front to our men, who steadily worked up it with heavy losses. The howitzers were now elevated a little to throw their shells over the hill; these fell among the Boer ponies, and caused the enemy much uneasiness at a very critical time. As soon as the whole hill was captured, our men began altering the sungars to face the other way; and when the artillery lookout men, with their long telescopes, saw them carrying stones, the gun-fire was turned elsewhere. This happened about 3 p.m.

Almost simultaneously with the capture of the whole of Pieter's Hill, our troops reached the railway cutting below the next hill, now called Kitchener's or Railway. An even heavier fire was directed on this than it had been possible to get at Pieter's Hill, as it was more nearly opposite our guns. A few men on Daly's Hill fired across, and enfiladed the Boer trenches; but there was one trench protected from this direction by a knoll, and in front of it our men lost heavily. The West Yorks moved up the ridge, but the Royal Lancasters on their left, who were to have attacked the neck between Kitchener's and Hart's Hills, moved too much to the west and attacked Hart's Hill with great dash. However the South Lancashires were close behind, and filled up the gap. Men dashed forward and held up their helmets on their rifles, as a signal to the artillery to give more elevation. A few men were hurt by our own shells, but there was no serious loss from this as on other occasions; and the infantry preferred the artillery to fire till the very last moment. General Kitchener even specially asked for this to be done.

Our men now began firing across from Kitchener's at the Boer trenches on Hart's Hill. These were also under a tremendous artillery fire. Some Boers retired from the trenches, but found the rifle fire from Kitchener's so severe that they sprang back again, eventually making off to the west. One Boer is said to have tried to rally them, and failing this to have stood on the parapet firing at our lines till he was blown to pieces with lyddite. The Boers in the trenches between Kitchener's and Hart's were now in a trap, and many prisoners were taken here, including two women. Meanwhile our men were climbing up Hart's Hill on three sides, and at last Lance-Corpl. Hannah, of the Royal Lancasters, rushed forward, stood up on the trench, and with his helmet on his bayonet signalled to the artillery to cease firing. The trench was found full of Boer dead and wounded and innumerable cartridge cases, and it must be allowed that the Boers had done all that brave men could to defend it.

Meanwhile, on the extreme right, the Boers opened fire from a kopje north of Pieter's Hill, but the Dublin Fusiliers carried it by a charge, losing 60. Thus the whole left of the Boer position was in our hands.

In the centre our men pressed forward and captured a Boer laager behind Hart's Hill, where they got a number of waterproofs and saddles. General Buller sent an order to Lyttelton, who commanded our left, to advance directly Warren's assault was successful; but unluckily the order miscarried, and thus the Boers remained in possession of hills from which they brought a severe fire on the advancing cavalry, who were consequently ordered back across the bridge.

Pursuit.

It is much to be regretted that the cavalry were not up at this moment, as the Boers were now in full flight over ground on which horsemen could work. In the event of a repulse the mounted men might have caused great confusion on the crowded left bank of the river; they could not follow the road, as that was under fire from the Boer centre, and all the ground between the river and the Boer trenches is extremely rough. Still the horses might have been led up the valley north of Terrace Hill, and been mounted just beyond the railway when the assaulting troops were getting close up to the trenches on Hart's Hill. The appearance of even one mounted regiment on the nek north of Hart's Hill would have converted the defeat of the Boers into a rout.

The enemy were thoroughly demoralized by this battle. They acknowledge it to have been the most expensive of the war to them. They lost heavily in men and stores, and were so impressed by the determination of our men that Boers who fought at Pieter's never fought well after. They raised the siege of Ladysmith, and practically cleared out of Natal; but the long halt round Ladysmith encouraged them to come back later on and occupy the Biggarsberg. But on our side the extent of the victory was not understood, though Buller telegraphed to Warren, "I congratulate you on the day."

The victorious troops made miles of new sungars, in case of counter-attack. It was expected that the Boers would hold the line of kopjies near Nelthorpe; and though this was rather close to their lines investing Ladysmith, it might have been defended. If pierced, their ponies would have enabled them to get away round one side of Ladysmith or the other.

Ladysmith Relieved, 28th February.

As it was they trekked on the night of the 27th. A few fought a skirmish with Thorneycroft's Mounted Infantry near Pieter's station on the 28th, but they were shelled out of their position by Horse Artillery, and Dundonald reached the Ladysmith outposts at dusk without serious opposition.

It would have been better if he had made a *détour* to the right and ascended Bulwana by its easy eastern slope. The Boers had a very big laager there, and the 3 guns on Bulwana might have been taken, as the northern slope was too steep to get them down. The practical relief of Ladysmith could only be accomplished by provision wagons, not by the riding forward of mounted men; and, the Tugela being still high, General Buller probably preferred to keep his scanty means of crossing for re-provisioning Ladysmith, rather than for supplying an army in pursuit of the Boers. But Natal had not been so thoroughly denuded as to prevent the cavalry and mounted infantry living on the country for at least a month.

The slackness of the pursuit greatly encouraged the Boers, who at first retired to the Drakensberg but afterwards came back and held the line of the Biggarsberg.

Remarks.

Our success at Pieter's was due to many causes, chief among which was the excellent co-operation of infantry, artillery and engineers. The tenacity of the infantry gained the footing on the left bank, and thus made possible the construction of the final pontoon bridge.

A large force was told off to the assault, which was made on a very wide front. The first point assailed was undoubtedly the weakest, both because our troops were able to work close up to it under cover, and because the Boer line there made a slight salient, allowing the attackers to use a wider front than the defenders. More troops coming up on either flank of those who had penetrated the position prevented the latter being driven back by a counter-attack, as has so often happened in warfare.

The artillery prevented the Boers aiming coolly, and, by watching the fight carefully, kept their shells a little in front of the advancing infantry. But their services during the actual fighting were almost equalled by their menace having compelled the Boers to take up so retired a line. If the Boers had entrenched the forward crest of Hart's Hill, they might have run a trench from its south-eastern to its north-eastern corner, and so held it after we captured Kitchener's Hill. The position of our force would then have been very awkward.

The worst of occupying the rear edge of a plateau is that probably no hill can bring much fire to its flanks. Consequently, when the position is penetrated at one point, and the attack on each side of this point well pressed, the gap can be continually widened till the whole position is captured. Thus it should never be made a *rule* to occupy positions on the reverse slopes of hills; nor on the other hand should a position be condemned because in one part the firing line must be so retired, especially if a clear field of at least 300 yards be secured. Trenches may even fire up-hill; and so placed they will be unassailable at night, as the assaulting troops will show up against the sky-line. But when retired positions are used, permanent garrisons must be told off to them and obstacles placed in front. Salients should be strongly fortified.

We should dismiss the idea that defensive positions can only be taken up on certain ground. Almost any ground can be held and made strong with entrenchments. Every sort of terrain has its advantages and its disadvantages; skill lies in recognizing these, and in disposing the troops so as to get the full advantage of the former whilst minimizing the latter. All disadvantages, except a short field of fire, can be removed by fortifying; it is only a question of time.

Such long-continued fighting as preceded the battle of Pieter's Hill is probably unprecedented in warfare. (The "7 days before Richmond" only lasted half the time). It involved a great strain on both sides, and our men stood that strain best. Besides the enemy's fire, they had to stand the hot sun by day and to sleep at night without greatcoats or blankets. Though the roar of several beautiful waterfalls could be heard in every lull of the firing, the men could generally only refill their water bottles at night. Often they had to lie all day in the same position under penalty of drawing a hot fire. But their sufferings only increased their dash when the time for the grand assault came, and Pieter's Hill should go down to posterity as one of the very finest achievements of the British army.

APPENDIX.

LIST OF TROOPS SENT FORWARD FROM CHIEVELEY ON 14TH FEBRUARY.

2ND MOUNTED BRIGADE (*Col. the Earl of Dundonald*).

South African Light Horse.
Thorneycroft's Mounted Infantry.
Composite Regiment, formed of :—

- 2nd Battalion King's Royal Rifle Corps, Mounted Infantry Company.
- 2nd Battalion Royal Dublin Fusiliers, Mounted Infantry Section.
- Detachment Natal Police.
- One squadron, Natal Carabiniers.
- One squadron, Imperial Light Horse.

2ND INFANTRY DIVISION (*Major-Gen. Hon. N. G. Lyttelton, C.B.*).

DIVISIONAL TROOPS.

One troop, 13th Hussars (?).
17th (Field) Company, Royal Engineers.
7th, 63rd, and 64th Batteries, Royal Field Artillery.

2ND BRIGADE (*Major-Gen. H. J. T. Hildyard, C.B.*).

2nd Battalion Royal West Surrey Regiment.
2nd Battalion Devonshire Regiment.
2nd Battalion West Yorkshire Regiment.
2nd Battalion East Surrey Regiment.

4TH BRIGADE (*Col. C. H. B. Norcott, 1st Battalion Rifle Brigade*).

2nd Battalion Scottish Rifles.
3rd Battalion King's Royal Rifle Corps.
1st Battalion Durham Light Infantry.
1st Battalion Rifle Brigade.

5TH INFANTRY DIVISION (*Lieut.-Gen. Sir C. Warren, G.C.M.G., K.C.B.*).

DIVISIONAL TROOPS.

One troop, 1st (Royal) Dragoons (?).
37th (Field) Company, Royal Engineers.
28th, 73rd and 78th Batteries, Royal Field Artillery.

10TH BRIGADE (*Col. J. Talbot Coke*).

2nd Battalion Somersetshire Light Infantry.
2nd Battalion Dorsetshire Regiment.
2nd Battalion Middlesex Regiment.

11TH BRIGADE (*Col. A. S. Wynne, C.B.*)

2nd Battalion Royal Lancaster Regiment.
1st Battalion South Lancashire Regiment.
Rifle Reserve Battalion.

6TH BRIGADE (attached 5th Division—*Major-Gen. G. Barton, C.B.*).

2nd Battalion Royal Fusiliers.
2nd Battalion Royal Scots Fusiliers.
1st Battalion Royal Welsh Fusiliers.
2nd Battalion Royal Irish Fusiliers.

CORPS TROOPS.

61st Howitzer Battery, Royal Field Artillery.
Two 5-inch guns (16th Company, Southern Division, Royal Garrison Artillery).
Four Naval 12-pr. guns.

NOTE.—Ammunition Columns accompanied the Divisional and Corps Troops; and a Section of the Telegraph Division was also included in the latter.

REINFORCEMENTS DESPATCHED AFTER 14TH FEBRUARY.

17th February.—Two 5-inch guns (16th Company, Southern Division, Royal Garrison Artillery).
18th February.—19th Battery, Royal Field Artillery.
19th February.—Two 4·7-inch Naval guns (travelling carriages).
20th February.—Four Naval 12-prs.
4th Mountain Battery, Royal Artillery.
"A" Pontoon Troop, Royal Engineers.
Balloon Section, Royal Engineers.

5TH INFANTRY BRIGADE (*Major-Gen. A. FitzR. Hart*).

22nd February.—1st Inniskilling Fusiliers.
1st Connaught Rangers.
2nd Royal Dublin Fusiliers.
Imperial Light Infantry.

1ST CAVALRY BRIGADE (*Col. J. F. Burn-Murdoch, 1st Royal Dragoons*).

22nd February.—1st (Royal) Dragoons.
13th Hussars.
Headquarters and two squadrons, 14th Hussars.
"A" Battery, Royal Horse Artillery.
25th February.—Two 4·7-inch Naval guns on platform mountings.
26th February.—1st Battalion Border Regiment (of the 5th Brigade).
27th February.—1st Battalion York and Lancaster Regiment (of the 11th Brigade).

There appears to have been one 4·7-inch Naval gun on a railway truck near Colenso.

Notes.

(1). 2ND MOUNTED BRIGADE.—Bethune's Mounted Infantry, belonging to this force, appears to have been detached on 11th February to watch the Boer left beyond Cingolo.

(2). DIVISIONAL TROOPS.—The 1st Cavalry Brigade, the 1st Battalion York and Lancaster Regiment and the Imperial Light Infantry, with two Naval 12-prs., were left at Springfield to cover the British extreme left; they appear to have joined the main force at Hlangwani on 22nd February.

(3). All the troops detailed in the above lists were not actively engaged in the fighting on the 27th February;—

(*a*). THE 1ST CAVALRY BRIGADE was on Hlangwani and the 2nd Mounted Brigade was held waiting east of the Tugela.

(*b*). The actual assaulting force of Infantry was disposed, from left to right, as follows:—4th Brigade, 11th Brigade, 6th Brigade; each brigade having extraneous battalions attached as shown below.

(*c*). 4TH BRIGADE, the 1st Durham Light Infantry was kept in reserve. See (*f*).

(*d*). 11TH BRIGADE.—The Rifle Reserve Battalion was posted on the N.W. slopes of Hlangwani, to the S.W. of the Railway Hill assaulted by the rest of the brigade. The 1st York and Lancaster appear to have rejoined this brigade on the 27th. See (*f*).

(*e*). 6TH BRIGADE.—The 2nd Royal Fusiliers and the 1st Royal Welsh Fusiliers lay north of Onverwacht spruit, guarding the left flank. The two remaining battalions were reinforced by the 2nd Royal Dublin Fusiliers from the 5th Brigade.

(*f*). 2ND BRIGADE.—The 2nd East Surrey were attached to the 4th Brigade, and the 2nd West Yorkshire to the 11th Brigade, for the attack on Terrace Hill. The 2nd Royal West Surrey and the 2nd Devonshire guarded the left rear of the attack on the kopjes between Onverwacht and Landerwacht spruits.

(*g*). 10TH BRIGADE.—These three battalions and the 73rd Field Battery held the kopje north of Colenso, guarding against a turning movement round the extreme left.

(*h*). 5TH BRIGADE.—The 1st Inniskilling Fusiliers, 1st Connaught Rangers and half the Imperial Light Infantry remained in the positions occupied by them after the attack on Hart's Hill on 23rd—24th February. The 1st Border, which rejoined on 26th, covered the advance from the east bank of the Tugela. See also (*e*).

(*k*). The greater portion of the Artillery—heavy, field and mountain,—ranged in an extended line, covered the attack from the eastern side of the Tugela.

PLATE I.

AP —

F LADYSMIT

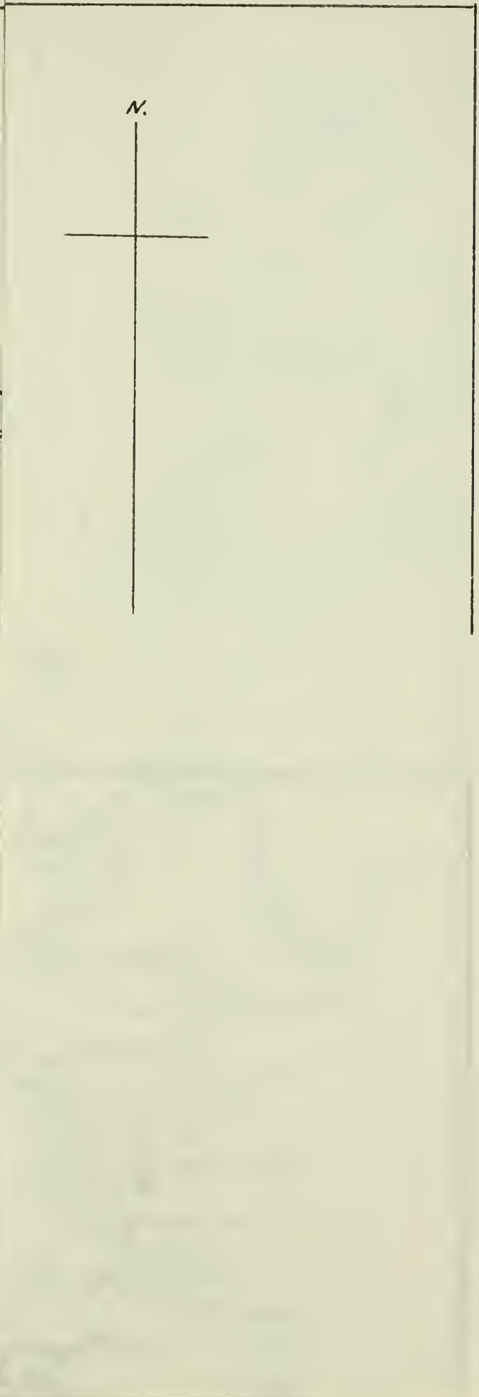


PLATE I.

—SKETCH MAP—
—OF—
—COUNTRY SOUTH OF LADYSMITH.—

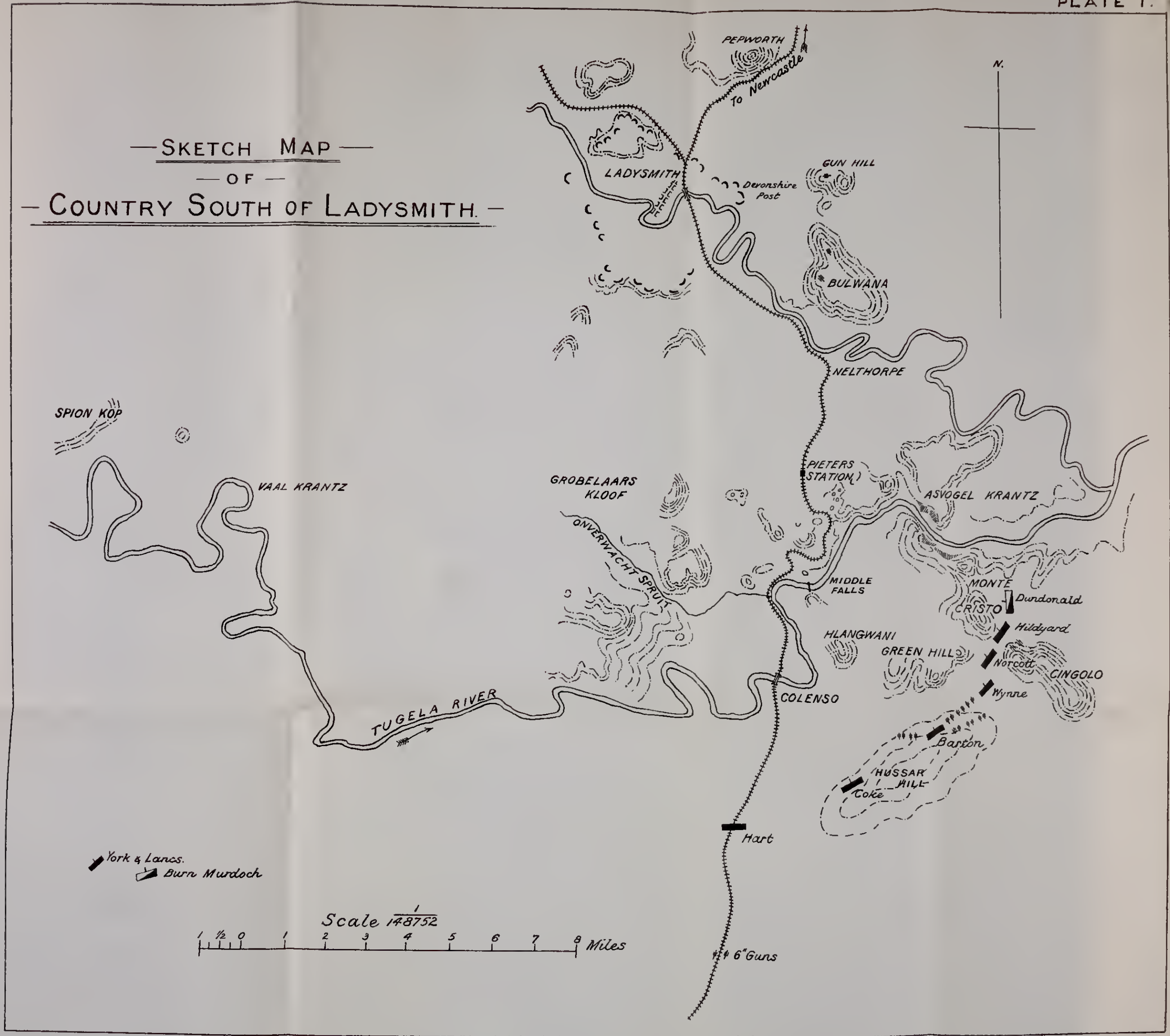
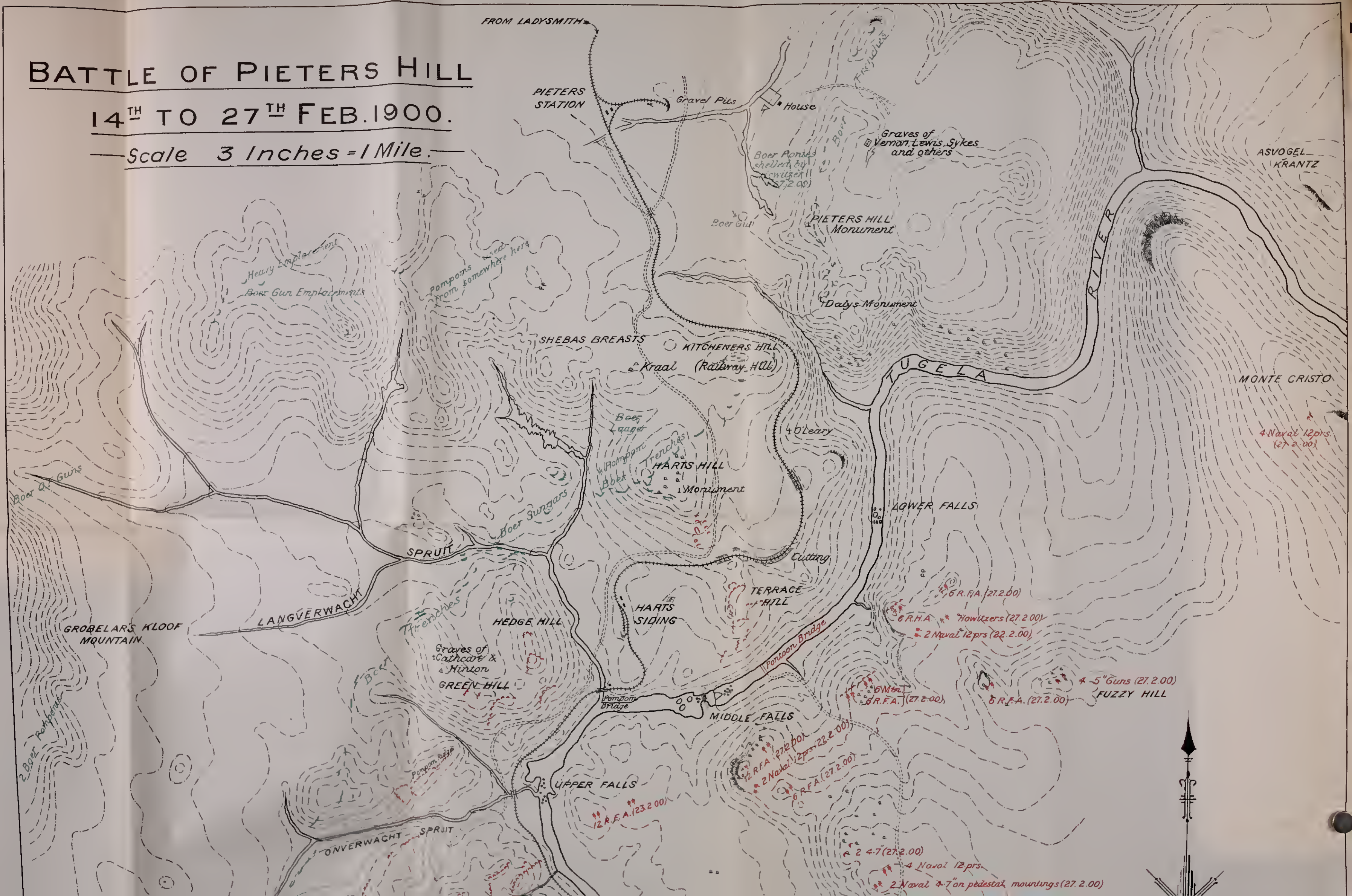


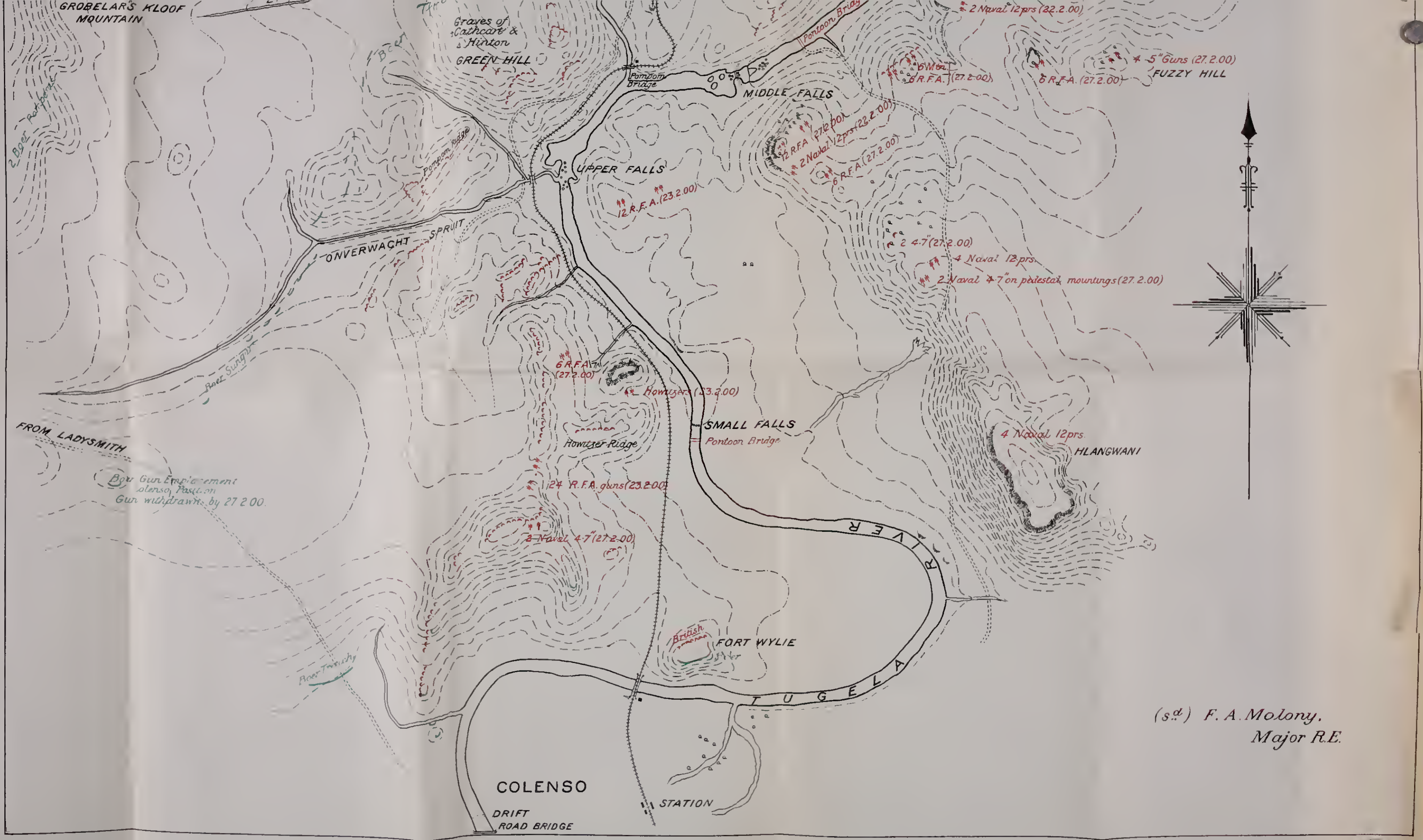
PLATE II.



BATTLE OF PIETERS HILL

14TH TO 27TH FEB. 1900.

Scale 3 Inches = 1 Mile.



(sd) F. A. Molony,
Major R.E.

PAPER XII.

THE BLOCKHOUSE SYSTEM IN THE SOUTH AFRICAN WAR.

BY

BT.-COLONEL E. H. BETHELL, D.S.O., R.E.

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THE BLOCKHOUSE SYSTEM IN THE SOUTH AFRICAN WAR.

Construction of Blockhouses.

Enemy's Attacks on Railway Lines.

As the British Army marched up to Pretoria in May—June, 1900, the lines of communication were left undefended; but very soon after its arrival there Commandant De Wet attacked the railway and caused a good deal of inconvenience to supply;—we were, in fact, living from hand to mouth.

Orders were then issued that all posts were to be fortified, and by the 1st July some kind of defence had been prepared at most of the important stations down the line.

The defences were at first usually trenches only; no one ever dreamt that the Boers would take to attacking at close quarters, and all that was thought necessary was to get cover from fire in the best available positions commanding the posts to be defended,—digging where the ground admitted of it, and making stone sangars when it did not.

At the end of July, 1900, De Wet escaped from the Brandwater basin, at the time of General Hunter's big haul, and attacked the railway again; he was pursued by Lord Kitchener in August, but, unfortunately for us, escaped through Olifant's Nek in the Magaliesberg which was not held.

The number of posts on the railway was increased, but attacks on the railway increased also.

Institution of Blockhouses.

The word "Blockhouse" began to be used about September, 1900, after Lord Roberts' return from Komatipoort. Exactly what it was intended to mean then I do not know; but a little later than this, before Lord Roberts went home, General Baden-Powell proposed a scheme for defending the railways by posts of ten men placed a mile apart along the lines.

At that time the Boers still had guns. Moreover, the proposed works did not seem suitable for prolonged day and night defence and permanent occupation ; they were to be low sunken works in which the garrison would have had, I think, an uncomfortable time if they had to remain under fire from several directions for a long period, and they had, of course, a very restricted field of fire except on level ground ; their obstacles consisted of nothing but the barbed wire fences surrounding them ; the loopholes, an important and essential part of any work of defence and especially of a very small work liable to heavy attack, was an ordinary extemporized loophole ; and cover from the weather, both sun and thunderstorms—almost essential for prolonged occupation, particularly with dug out works which would fill with water—was absent. It must, of course, remain a matter of opinion and surmise whether these works would have fulfilled their object, but at any rate the general idea was very much the same as that afterwards adopted,—in fact some such plan was literally forced upon us.

Earliest Pattern of Corrugated Iron Blockhouses.

The wrecking of the railways reached a maximum in November and December, 1900, and the first blockhouses were put up for us by a Lorenço Marques contractor, in January, 1901; only some half dozen, at Nelspruit, Kaapmuiden and Komatipoort.

They were oblong, about 9 or 10 feet by 15 feet, consisting of two rows of posts, 3″ × 3″ and 2 feet apart, with a skin of corrugated iron fixed to each row, and stony sand filled into the space between the skins ; the loopholes were 3″ × 4″ holes in steel plates, 2 feet wide and 9 inches deep, and were fixed in wooden casings placed in openings cut in the corrugated iron walls ; a corrugated iron roof completed the structure.

The door was traversed in the usual way, a water tank provided, and the whole surrounded by an entanglement of wire.

The result was a very good blockhouse, but one which required a lot of material and much time to erect, and for which the steel plate loopholes were not obtainable quickly in sufficient numbers.

It would not have been possible, in the time available, to develop the cross-country blockhouse system to the extent to which it was developed, had not something less cumbrous been invented.

Rice Pattern Blockhouses.

About February, 1901, Major S. R. Rice, R.E., Commanding 23rd (Field) Company, hit upon the idea of fixing corrugated iron to both sides of wooden frames 4½″ thick, stuffing the space between with hard shingle.

He used eight frames to each (octagonal) blockhouse ; the ends of the frames were bevelled to the right angle ; and the inner skin of corrugated iron was blocked out at the corners on wooden blocking pieces, so as to give 4½″ of hard shingle between the inner skin and the vertical parts of the wood frames.

The frames were simply placed on a level platform and bolted together, the outer skin being put on as the filling proceeded ; thus no post holes were required. A square gable roof was placed over all.

The loopholes were ingeniously cut out of sheet iron, and constructed so as to give a loophole, 6″ high and 3″ wide at the neck, in the centre of the shield, the outside and inside of the loopholes being the wide ends of two funnels with a common neck in the middle. They worked well in practice ; there were few, if any, authentic cases of bullets striking the cheeks and penetrating. Holes had to be left in the sides of the loopholes to allow of putting in more shingle as the filling settled ; several men were shot by bullets which passed through under the sills after the filling had subsided. Other Commanding Royal Engineers had their own ways of making the loopholes, for the most part simpler than Major Rice's and giving the same result.

Major Rice's company, then at Middelburg in the Transvaal, soon became an extremely well-organised blockhouse factory, the construction of each separate part being in the hands of the same men.

Every part was made to template, and, consequently, these blockhouses all fitted well together, which was far from being the case with those made by contract at the coast. The gable roofs were useful for ventilation, and were much cooler than the umbrella-shaped roofs adopted in some parts, but were heavier and required more material. The canvas roof with a pole, which was much used later, was considerably lighter.

Circular Blockhouses.

Before long Major Rice invented his circular blockhouse, which was a very great advance on the octagonal type.

The circular type required no woodwork in the shield except small blocks, 6″ × 6″ × 3″, to keep the skins of corrugated iron the right distance apart and to give a means of attaching the roof.

This pattern had great advantages, and meant less material, less work in the shops, less transport, and easier fitting together in the field. It was also much stronger than the octagonal pattern, in which the corrugated iron in the frames used to bulge when filled with shingle; the circular type moreover had no vertical timber in the shield, requiring a special device to make the shield bullet proof where the timber occurred.

All the sheets had to be curved, in a machine costing about £60 to £70; it was probably from watching the manufacture of the cylindrical corrugated iron water tanks with one of these machines that Major Rice got the idea of the circular blockhouse.

Stone Blockhouses.

Meanwhile Major-General E. Wood, Chief Engineer, had designed a form of two-story stone blockhouse with steel plate loopholes, for erection at important points such as railway bridges. These, of course, took a long time to build.

As soon as Lord Kitchener heard of the pace at which Major Rice could turn out the octagonal blockhouses, he pressed on their construction on all the railway lines to safeguard the railways. General Wood had drawings and descriptions of the blockhouses sent to all C.R.E.'s, and they were started all over the country; but before long the circular type became the general pattern.

Either the drawing of the circular blockhouse was not as explicit as it might have been, or else the idea of dispensing with timber in the shield was not grasped at first; anyhow, I never saw a single blockhouse made anything like right until models had been sent round.

The blockhouses coming from the coast, and made by contract, were of weird patterns, with timber uprights outside the walls and strange loopholes, and continued so for a long time.

Soon, however, factories were started at many Company headquarters, *e.g.*, at Bloemfontein by Lieut.-Colonel P. T. Buston, R.E., with Major J. S. Purvis, R.E., in charge. Civil labour was employed by Major Purvis, and this, as military labour, gave decidedly better results than the contract system, except, perhaps, at Pretoria, where Lieut.-Colonel R. C. Maxwell, R.E., had all his contract blockhouses put up on trial before they were sent out.

Sentry Trench.

It was found necessary, as a general rule, to surround each blockhouse by a sentry trench about 4′ 6″ deep, both to protect the sentry and also to give the garrison a place from which they could often bring more fire to bear on an enemy than was possible from the blockhouse loopholes.

Outside the trench, which was 2 to 5 yards from the blockhouse, a barbed wire entanglement was made.

General Alteration of Defences.

The blockhouses were not the only defence work being carried out by the Royal Engineers in the first half of 1901.

It had become absolutely necessary to revise all the defences of stations on the railway lines and elsewhere by substituting, for scattered lines of shelter trench, closed works erected at the angles of the protected area and giving a cross fire over the intervals.

Positions treated in this way could be made very strong with but few men. The Boers learnt to press attacks against localities held by shelter trenches and sangars; but they generally eschewed the attack of closed works with plentiful barbed wire round them and good loopholes. They never attempted to ignore the closed works and penetrate the intervals between them, as these works supported each other by cross fire and greatly increased the difficulty of capture. It took, of course, a long time and repeated explanation to get this fact appreciated.

Movable Blockhouses.

Though independent of the blockhouse system, it may be mentioned that some of the R.E. Companies fitted up shields on ox-wagons, and thus converted them into movable blockhouses for use with convoys, or for "stopping" some point where the Boers crossed the line.

Railway Blockhouses.

The blockhousing of the railways was in full swing by the end of March, 1901, in the Transvaal and Orange River Colony, and in July a great effort was made to blockhouse the lines from Orange River—De Aar, Naauwport—Stormberg, and Naauwport—Norvals Pont. This was when De Wet's second attempt to invade Cape Colony was expected.

The construction of these blockhouses was started by General Wood at all Company headquarters and at all the ports; parties of Sappers and truck loads of blockhouses were sent down to the projected lines from every R.E. company in South Africa. The allotment on arrival, and the railway arrangements for distributing the material and labour, were carried out by Major F. C. Heath, R.E., who was General Inigo Jones' Chief Staff Officer.

The blockhouses were put up often at the rate of six a day by each party. There were in all 387 blockhouses, and the bulk of them were erected in a month.

On the Orange River—De Aar section Captain G. M. Hutton, R.E., first got the walls built up and filled and the blockhouse occupied, and added the roofs later; he had much trouble with the loopholes, the Cape Town blockhouses not having the sheets cut to receive them, necessitating this being done on the spot.

The erecting parties were of very various composition in this case, some being superintended by the Company Tailor; but to put up a blockhouse complete, with its sentry walk cut out, its wire entanglement finished, and everything ready, took a party of 3 Sappers and 20 Infantrymen and native labourers from 6 to 9 hours.

Cross-Country Blockhouse Lines.

In June, 1901, the first cross-country blockhouse line was planned by Lord Kitchener from Groot Olifant's River station on the Komati Poort line to Val station on the Natal line. A battalion of Infantry was detailed as escort and to assist the erection at each end, and the R.E. parties with their blockhouses and the transport were ready to begin, when Lord Kitchener ordered the whole to go west to Frederickstadt and run a line up the Mooi river to its source and thence across to Naauwpoort; this line was begun in July and finished in August.

The next line was begun at both ends from the junction of the Mooi and Vaal rivers to Kopjes station on the Orange River Colony railway; the Oxfordshire Light Infantry with R.E. parties worked from Kopjes, and the 2nd Grenadier Guards, with Capt. R. N. Harvey, R.E., and his detachment of Sappers, from the Mooi end. This line had not long been completed when Lord Kitchener wanted it moved forward, as he thought the piece of country between the old line and the Vaal was well cleared and that the Boers would not again enter it.

The new line was to be along the Rhenoster river from its junction with the Vaal to Witkop, and thence to Lace Diamond Mines, to which a line had already been run from Kronstadt.

Lieut.-Colonel P. T. Buston, R.E., found it best to despatch new blockhouses for the new line, and have the old ones brought into Kopjes and railed to Bloemfontein for repair and re-issue; the Rhenoster line was erected first by two battalions and the R.E. sappers, and then the Lace Mines — Witkop portion from the Kronstadt end.

Last of all Lord Kitchener ordered a line from Lace Mines along the Valsch river to Bothaville, the Witkop—Rhenoster line being demolished; this new line was commenced on the 6th December and finished on the 19th February, 1902.

On reaching Frankfort on 12th November, 1901, I found Colonel Rimington there with a Column, and he was most anxious to have the line extended to Tafelkop, which he thought a fine eyry for the Boers and one of their regular signal stations; he considered that the communication they were able to keep up by this means from north to south of the western portion of Orange River Colony an important feature in their operations. The line Heilbron—Frankfort was at that time just about completed.

This being represented to Headquarters a new line was commenced on the 26th November and reached Tafelkop on 29th December. It contained 47 blockhouses in the 23 miles, 7 being on and around Tafelkop. Transport invariably determined the speed of progress.

Meanwhile a line had been completed on 30th December from Ikateni, near Majuba Hill, to Botha's Pass; on 3rd January the line from Tafelkop was continued to a point 9 miles or so south of Vrede, and finished on 31st January, while from the other end of the gap a line was made from Botha's Pass to the same point.

For the line Frankfort to Botha's Pass, about 87 miles, there were 187 blockhouses, garrisoned by 2,558 men, or 30 men to the mile.

Other lines were :—

(1). Kronstadt—Lindley : 50 miles with 108 blockhouses and 4 posts. Commenced 18. 11. 01, and finished 9. 1. 02 ; with a branch from Kaalfontein to Valsch river bridge, 8 blockhouses.

(2). Lindley—Bethlehem, *viâ* Kaffirkop and Naude's Kop; 80 miles, 94 blockhouses with the following garrison, viz. :—

4th Rifle Brigade	482	men
2nd Queen's	764	,,
1st Inniskillings	688	,,
Total	1,934	,,

or 24 men to the mile.

(3). Harrismith—Bethlehem; 50 miles, 134 blockhouses and 2 posts. Bethlehem bridge—Bethlehem ; 4 miles, 17 blockhouses.

On this section there were :—

South Staffordshire Regiment ...	530	men
1st Black Watch ,, ...	385	,,
East Yorks ,, ...	496	,,
King's Royal Rifles	483	,,
Total	1,894	,,

or, in the 50 miles Harrismith—Bethlehem, 38 men to the mile.

(4). Elands River—Elands River bridge; 10 miles, 20 blockhouses.

(5). Van Renans—De Beers—Platberg; 20 miles, 31 blockhouses.

(6). Harrismith—Olivier's Hoek; 23 miles, 16 blockhouses.

(7). Bethlehem—Brindisi; completed 31. 1. 02, 40 miles, 47 blockhouses.

Volksrust—Wakkerstroom; 18 miles, 21 blockhouses.

(8). Wakkerstroom—Derby; 70 miles, 100 blockhouses, with posts at Castrol's Nek, Mabola, and two other points. On this line there were :—

North Staffordshire Regiment ...	150 men
West Yorks ,, ...	662 ,,
Scots Guards	712 ,,
Total	1,524 ,,

or, in the 70 miles, 21 men to the mile.

(9). Standerton—Ermelo; commenced 11. 11. 01, finished 20. 1. 02, 56 miles, 131 blockhouses and 6 posts.

Ermelo—Carolina; commenced (from each end) on 21. 1. 02, finished 9. 2. 02, 34 miles, 85 blockhouses. On one section of this line, comprising 73 miles, there were :—

1st Leicestershire Regiment	902 men
1st Essex ,, ...	800 ,,
Royal Irish Fusiliers	530 ,,
Total	2,232 ,,

or, say 30 men to the mile.

(10). Wonderfontein—Carolina; commenced 30. 12. 01, finished 17. 1. 02, 25 miles, 55 blockhouses and posts.

(11). Eerste Fabrieken—Groot Olifant's River; 55 miles, with 1,700 men, or 30 to the mile.

(12). Ermelo — Bankop—Amsterdam; finished to Bankop at armistice on 29th March.

(13). Frederickstadt—Naauwpoort; commenced July, 1901, finished August, 1901, 44 miles, 37 blockhouses.

(14). Wonderfontein—Komatipoort; along the railway, 175 miles, with 3,200 men, or 18 men to the mile.

(15). Rooidrai (Mooi River)—Ventersdorp; 19 miles, 21 blockhouses, commenced 19. 12. 01, finished 5. 1. 02, demolished 12. 2. 02.

(16). Vaal River—Ventersdorp; 50 miles, 56 blockhouses and 3 posts, completed 9. 12. 01, with 491 men, or 10 men to the mile.

(17). Ventersdorp—Tafelkop; 27 miles, 59 blockhouses and 3 posts, commenced 19. 12. 01, finished 31. 1. 02, garrisoned by 689 men, or 25 men to the mile.

(18). Tafelkop—Naauwpoort; commenced 12. 2. 02, finished 4. 02, 45 miles, garrisoned by 566 men, or 12 men to the mile.

(19). Buffelsvlei—Lichtenberg; commenced 19. 1. 02, finished 20. 2. 02, 40 miles, 79 blockhouses and 2 large posts, with officers at 11 of them, garrisoned by:—

Border Regiment	709 men
L.N. Lancashire Regiment	302 ,,
Total	1,011 ,,

or 25 men to the mile, including Lichtenberg garrison.

(20). Mafeking—Lichtenberg *viâ* Polfontein.

(21). Polfontein—Maretsani.

Machadadorp—Lydenburg; line of posts from 3 to 9 blockhouses each, 45 miles, 55 blockhouses.

(22). Vaal River (Kroomdrai—Bothaville); 9 posts.

(23). Dundee—Vryheid; 40 miles, 73 blockhouses.

(24). Victoria Road—Carnarvon; 80 miles, 112 blockhouses and 3 posts, commenced 14. 12. 01, finished 24. 1. 02.

(25). Carnarvon—Williston; commenced 25. 1. 02, finished 20. 4. 02.

(26). Williston—Calvinia; commenced 3. 5. 02, finished 31. 5. 02.

(27). Calvinia—Clanwilliam; commenced 15. 1. 02, finished 28. 5. 02.

(28). Clanwilliam—Lambert's Bay; 34 miles, 53 blockhouses, commenced 14. 12. 01, finished 15. 1. 02.

(29). Bethulie—Herschel; 80 miles, 6 posts and Aliwal North.

(30). Bloemfontein—Maseru; 82 miles, 79 blockhouses (including posts), divided into three sections:—(i.) Bloemfontein—Sanna's Post, 20 miles, 17 blockhouses, 288 men; (ii.) Sanna's Post—Thaba' Nchu, 20 miles, 25 blockhouses, 467 men; (iii.) Thaba' Nchu—Maseru, 42 miles, 37 blockhouses. In (ii.) there were also 4 posts on the hills between Vaalkrust and Victoria Nek and 6 round Thaba' Nchu. In (iii.) Springhaan's Nek, Karmel, Crimea, Uitwaltz, Babfontein were occupied.

(31). Lines of posts connected Dundee with Weltvereden, and Donkerhoek with Bantris.

Plates I. to XVI. show types of blockhouses, fencing, alarm guns and signals, alarm flares, and fixed rifle batteries. *Plate* XVII. shows the blockhouse lines in the theatre of war at the end of March, 1902.

Intervals between Blockhouses.

The blockhouses were at first put up 1½ miles apart, and even thus had an enormous effect in stopping the destruction of the railway line, bridges and trains; but with such large intervals it was impossible to make a serious obstacle to Boer parties crossing at night. Later on they were generally placed ¾ mile apart, but in some cases, as on the Ermelo-Standerton line, the interval was reduced to 700 yards.

Given sufficient troops, of course, the shorter the interval the better; but when once you get the centre of the intervening space between blockhouses within "fixed sights" range of both, there is, I think, no advantage in reducing the distance further except the proportionate advantage due to the greater number of rifles.

Fences between Blockhouses.

The fences between blockhouses were a great and increasing difficulty, as the Boers found a way of cutting through or overturning by night whatever we put up.

We began with the slightest barbed wire fence. We increased this to a more formidable obstacle by adding "aprons" on each side, *i.e.*, 3 or 4 horizontal wires on each side secured to the sloping stays of the standards. Then we tried twisting up several strands of barbed wire (3 or 4) so as to make a thick rope; to make this the wires were secured to two standards about 8 to 10 yards apart, hanging down to the ground between, and were then twisted up with a rack stick; the barbs of the wire caught each other and kept the rope together, the rack stick being afterwards withdrawn.

Next we tried thick unannealed steel wire, ¼″ thick; this was uncuttable by most wire cutters, but could be severed at a single blow by an axe or hatchet; when the Boers found it difficult to get through this they turned the fence right over, cutting and pulling up the stay pegs; we then anchored the stays in the ground to buried stones and sandbags. The labour of all this may be imagined, as there were 400 stays required for every mile, with 400 anchorages.

The garrisons were frequently only 1 N.C.O. and 5 or 6 men; it was difficult to persuade officers or men that with blockhouses ¾ mile apart anything useful in the way of digging could be effected by such small garrisons, who always had to find a sentry and the necessary fatigues; I could only say, in explanation of Lord Kitchener's orders, that they might still be sitting on that blockhouse line when another year had gone by, and that a little work done regularly every day (by carefully organizing the daily duties and arranging for men who had been up at night to get a clear 6 or 8 hours sleep in the day) would mount up to a great deal at the end of a year.

I do not think digging was of much use in its early stage, when the ditch was only about 3′ wide and the same deep; but when it became 5′ wide and 4′ deep,—the earth being all spread, or half of it spread and the rest banked up between two such ditches—it became a difficult obstacle.

Devices for Alarms, etc.

A great variety of dodges were tried, for giving warning to the blockhouses when the Boers were tampering with the fences and for enabling the garrisons to direct their fire correctly.

(1). *Alarm guns* were fixed to the posts of the fences at several points and connected with a thin trip wire running parallel to the fence. Guns were also fixed to the posts with the trigger connected by a piece of thin wire to one of the fence wires, so that when the wire was cut it sprang back and discharged the gun.

Such devices were gradually displaced by guns, which were fixed close to the blockhouses, and were fired by the cutting of a long thin wire stretched right along the fence with a heavy stone hung to it at the blockhouse, a piece of thin wire connecting the trigger to this long wire. Sometimes the fence wires themselves were made to run through loops on the posts and act in the same way. Both these last dodges were necessary because the Boers generally spotted the guns whilst still at a distance from the blockhouses and disconnected them.

Friction tubes were also used as alarms, but not very successfully, as they required to be pulled with a jerk,—not merely dragged out.

(2). *Chemical alarms* were also tried. In these, when the wire was cut, it broke a small phial, which emptied its contents into another chemical and either caused a detonation or lit a flare. These were, however, no better than an ordinary detonating cap, which could be made either (i.) to light some fine powder or gun-cotton, and so some cotton waste and rosin mixed, or (ii.) to fire a cartridge.

Alarms were made to detonate either by the release of a weight which dropped on to a striker (*e.g.*, a nail) placed over a cartridge; or by dropping the detonator itself, the case containing a small weight, and the detonator being fired by the momentum of the inside weight striking the ground.

Fixed Rifle Batteries.

It was one thing to get an alarm which would work, and to be sure the garrison would hear it on a windy night; but another thing to enable them to shoot straight down the fences—the only chance of hitting anyone in the dark.

To this end wooden biscuit boxes were embedded in the parapet of the sentry trench,—or, better still, in a small defiladed recess leading out of it—with grooves cut fore and aft, filled with shingle, and so laid that a man had nothing to do but place his rifle straight in the grooves and shoot.

Latterly General Wood ordered the construction of fixed batteries made to hold 2, 4 or 6 rifles, all laid along the fences and all fireable by one man at once. These, however, required spare rifles which were not always obtainable.

Forked sticks stuck into the parapet inside and outside the shield, and adjusted for shooting down the fences, were also tried.

Cost of Blockhouses.

(1). *Contracts Made at Cape Town by C.R.E., Cape Colony.*

		£	s.	d.
Circular blockhouse with tent roof		22	0	0
Erection, including travelling		12	0	0
		£34	0	0
Circular blockhouse with gable roof		30	0	0
Erection...		14	0	0
		£44	0	0
Entanglements round blockhouse.	Material ...	15	0	0
	Labour ...	8	0	0
		£23	0	0
Entanglements between blockhouses 1,500 yards apart.	Material	48	0	0
	Labour	53	0	0
		£101	0	0

The cost of the Cape Town blockhouses was very high; but they were not of the simple "Rice" pattern, and they required much more material without having any corresponding advantages.

(2). *C.R.E., Pretoria's Contracts.*

Circular blockhouse with C.I. roof complete.	£	s.	d.
Materials (at *coast* price)	16	15	6
Labour	9	10	0
	£26	5	6
Add railway charges for materials	10	18	6
	£37	4	0
Circular blockhouse made by Major Rice with R.E. labour ... ... about	16	0	0

Materials taken at coast price at Delagoa Bay, and including no labour.

Cost of an average entanglement between blockhouses, at coast price, put up by the troops. Per mile	50	0	0

Entanglements, however, varied in pattern; on some of them great quantities of wire were expended, while others were simple.

There were over 8,000 blockhouses of all sorts, and the total length of blockhouse lines amounted to about 3,700 miles. The whole cost of the blockhouses, with all their entanglements, must have been well under £1,000,000.

STRATEGICAL ASPECT OF THE BLOCKHOUSE AND COLUMN SYSTEM.

The question of strategy involved in the blockhouse and column system has been discussed.

Railway Blockhouses.

As regards the blockhouses on the railways no further justification of them is needed than the protection they afforded to the railways and the trains. The wreck of a single mail train meant a loss of at least £20,000. The constant cutting of the line and burning of the bridges made it difficult to get enough supplies up the lines, and was a serious as well as expensive matter.

Cross-Country Blockhouses.

The strategy of the cross-country blockhouses has been freely criticized. It has been said that the object of all strategy is to bring an overwhelming force against the enemy at the critical point; whilst the blockhouse system involved the dispersion of all the available men all over South Africa, so that they could be strong nowhere, and was a system requiring no skill in the use of those numbers.

This criticism leaves out of account several essential factors of the case.

Firstly, the blockhouse lines were always the containing lines, while the columns were the striking force that needed the power of concentration; secondly, the infantry in South Africa was useless for catching Boers, and certainly could not have been employed so effectively in any other way other than in holding defensive lines. At particular times and in particular places, such as in hunting through the valleys, holes and dens of the Magaliesberg, infantry did good service and accounted for many surrenders; but in general when they accompanied the columns they trekked about guarding the baggage and seeing no Boers. Again, the blockhouse lines could not have been held at all except with modern arms, and were a means of taking advantage of the great power of the rifle on the defensive.

Lastly, what were the possible alternatives? I know of only one:—Blockhouse lines might have been built to all the principal centres to protect the convoy lines, and these centres might have been strongly held as pivots for movable columns. No doubt columns issuing from fairly comfortable quarters would do much more in the way of rapid surprise raids, and put much more go into them, than columns everlastingly on the trek; in fact many small captures were made in this way, *e.g.*, by Colonel Barker centred at Winburg, and also by Colonel Benson who kept the Boers in constant fear of his rapid and vigorous movements. But the Boers soon began to be on the *qui vive*, and constantly changed their bivouacs.

Such a plan as this would, however, have involved the separate action of each separate group of columns centred at one place, and if the Boers had been able to combine on a large scale they might have overwhelmed such columns; at any rate joint action would have been more difficult for us, and the war would have been to a much greater extent taken out of the control of the Commander-in-Chief. The plan actually adopted seems to be the most sound.

The great difficulty of the "drives" on to the blockhouse lines was that the Boers took good care not to get driven on to them in daylight and were able to avoid this. It was impossible to prevent their crossing at night, though no doubt they got to like this less and less as the lines got stronger and stronger; the distance over which the line of columns moved in a day, when the crossing was near, was small, and the Boers took care not to remain in front of a blockhouse line within that distance.

The blockhouse lines were not only of value as containing lines and as affording protection to convoys (though this last was very remarkably great in proportion to the real power of the blockhouses); but also in preventing the Boers massing without our knowledge, and in denying to them the use of the rivers for water and of the great natural features of the country for signal stations, *e.g.*, Platberg, Retief's Nek peak, Tafel Kop (O.R. Colony), Tafelkop (Transvaal), Ermelo Kopje, Kaffir Kop, and many others.

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Corrugated Iron Blockhouse with Earth Revetment (Kaalfontein)	2	,,
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,, ,, Signals...		XI.
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,, Circular Corrugated Iron ,, ...		XV.
,, Hexagonal ,, ,, ,, ...		XVI.
Sketch Map of South Africa, showing Blockhouse Lines and Posts at end of March, 1902		XVII.

REMARKS ON ILLUSTRATIONS.

The illustrations were prepared and arranged by the Editor from photographs and drawings kindly supplied by various officers, to whom the author of the Paper desires to convey his thanks. The *Plates* are typical of the works constructed, but are not necessarily types of the best patterns.

Colonel Bethell, who was Assistant Adjutant General R.E. on the staff of the Chief Engineer and subsequently Inspector of Blockhouse Lines, makes the following remarks:—

Plate XIV.—"Except when hardened steel was procurable, the plates used for the machicouli galleries and the loopholes were ½" thick."

Plate XVII. (This is a reduced copy of a map compiled at the date stated thereon. On account of the smallness of the scale the hill features, which of course had a direct bearing on the location of many of the cross-country Blockhouse lines, have been omitted).

> "(i.). I do not remember a regular series of Posts through Swaziland. I believe there were a few, held by irregulars, along the Selati R. north of Komati Poort. I have no knowledge of the two that are shown due east of Lydenburg.
>
> (ii.). The length Machadadorp—Lydenburg was held by Posts and not by a line of Blockhouses.
>
> (iii.). There was no Blockhouse line running east from Rustenburg to Rietfontein, but detached Posts were established along the Magaliesberg at the passes east of Olifant's Nek. The Blockhouse line northwards from Naauwpoort did not run in to Rustenburg, but up to Olifant's Nek. A Blockhouse line was erected from Tafel-kop to Naauwpoort, and when this was completed the lines from Naauwpoort and Welverdiend to Fredericksstad were dismantled.
>
> (iv.). The Western railway was regularly Blockhoused all the way up to Maretsani (just north of Maribago), and thence a line was carried across country to meet the Mafeking—Lichtenburg section at Polfontein.

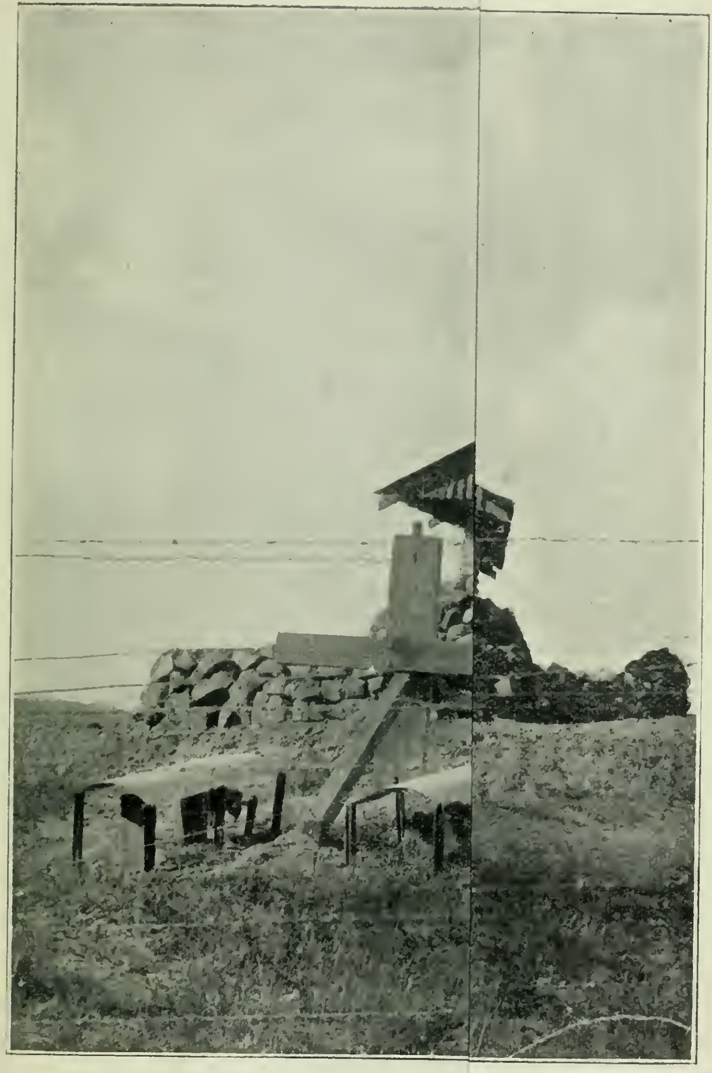
(v.). There was a Blockhouse line (as shown) along the Valsch R. up to its junction with the Vaal, but along the Vaal there were only Posts at the fords. The line from Lindley to Bethlehem ran southwards by Kafir-kop, and not direct.

(vi.). The Blockhouse line east of Warringham ran direct to the Caledon R.; between Warringham and Ladybrand there were only a few Posts.

(vii.). The length Bethulie—Springfontein was fully Blockhoused."

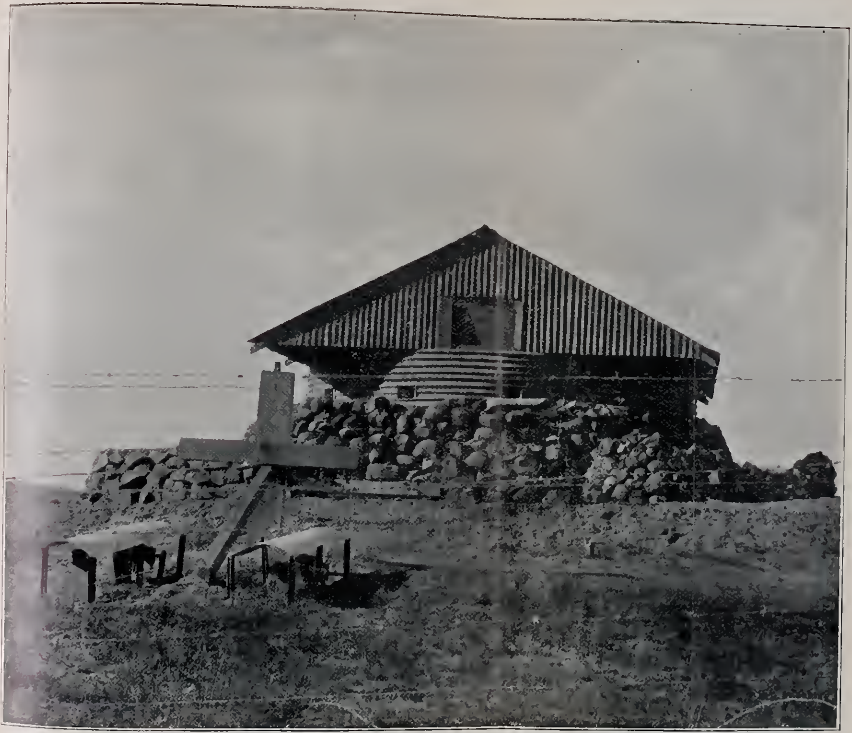
Erratum.—Plate XVI. has been erroneously headed "Rectangular" instead of "Hexagonal."

PLATE I.



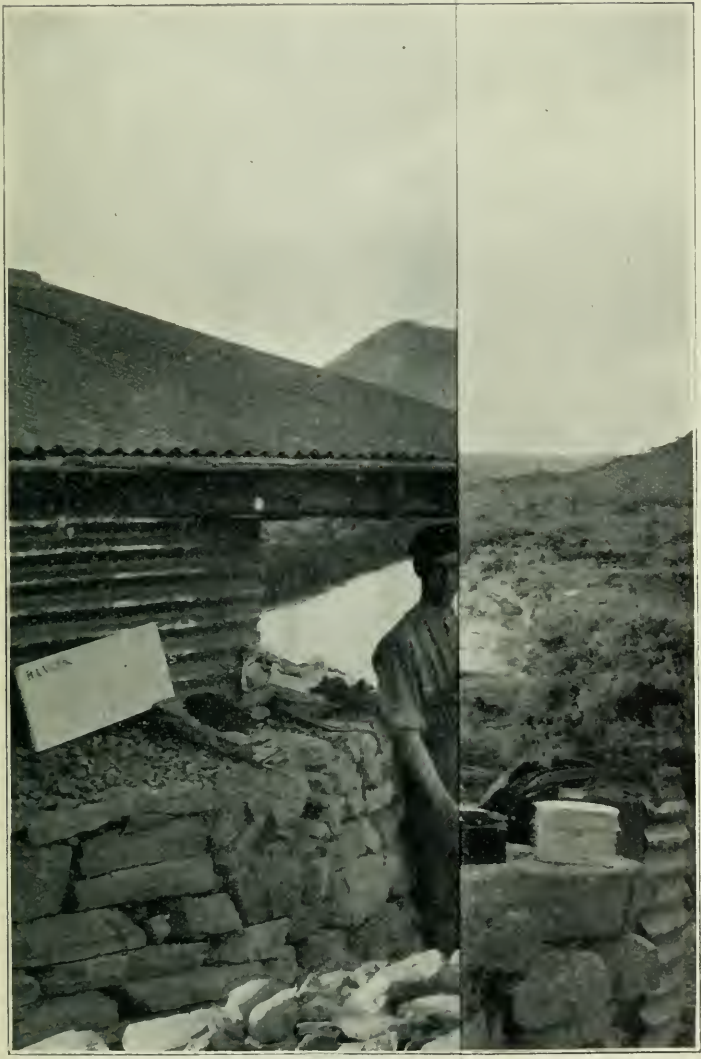
Blockhouse

PLATE I.



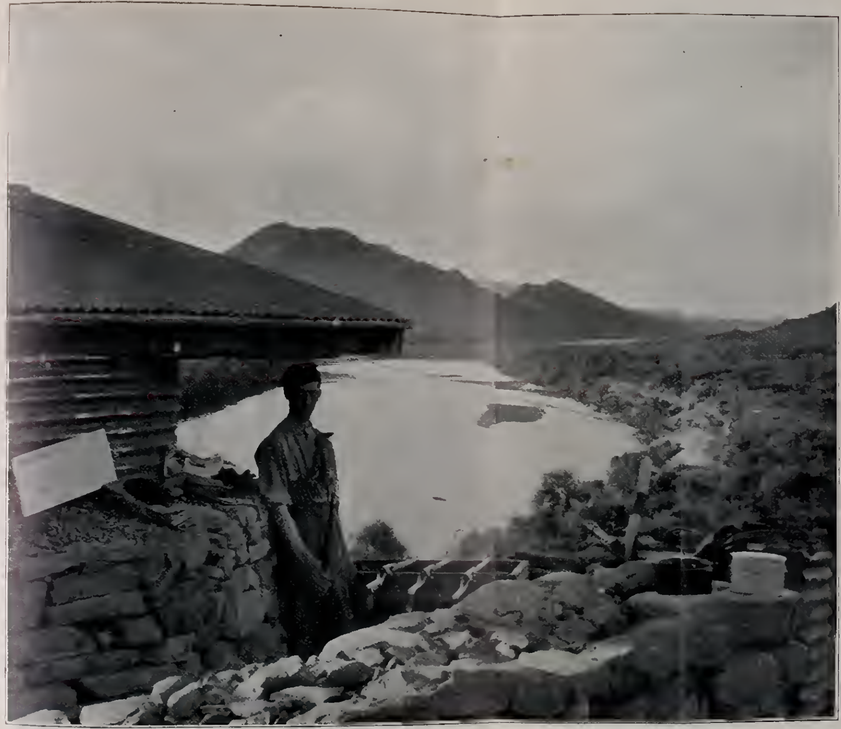
Blockhouse with cart-spring alarms, west of Aliwal.

PLATE II.



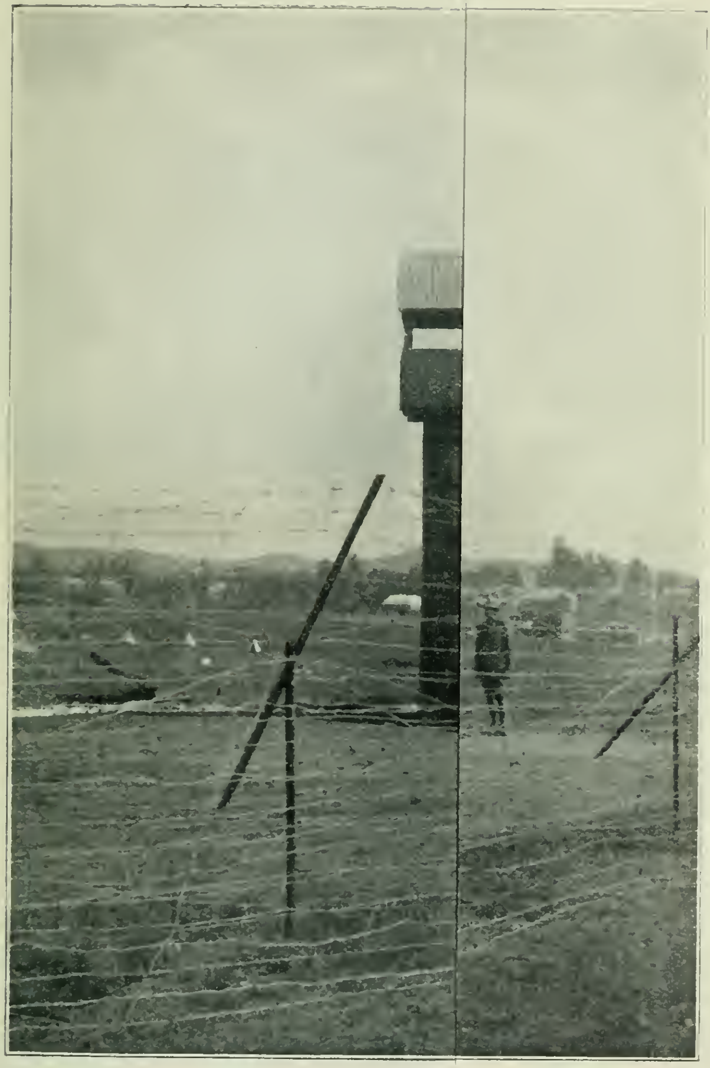
Blockhouse,

PLATE II.



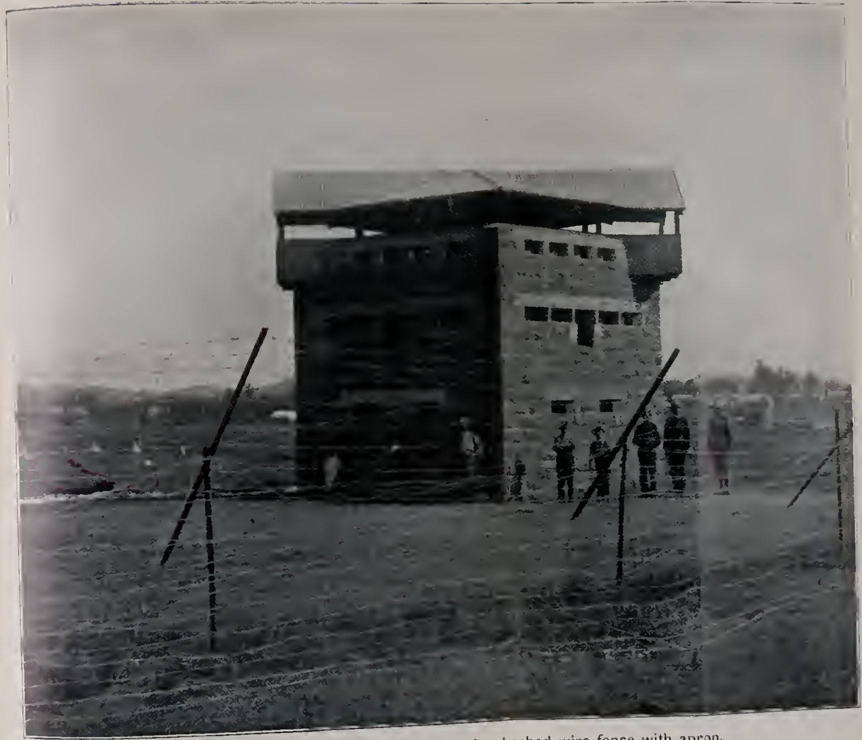
Blockhouse, west of Aliwal, showing fixed rifle battery.

PLATE III.



Masonry Blockhouse (on.

PLATE III.



Masonry Blockhouse (N. of Aliwal), showing barbed wire fence with apron.

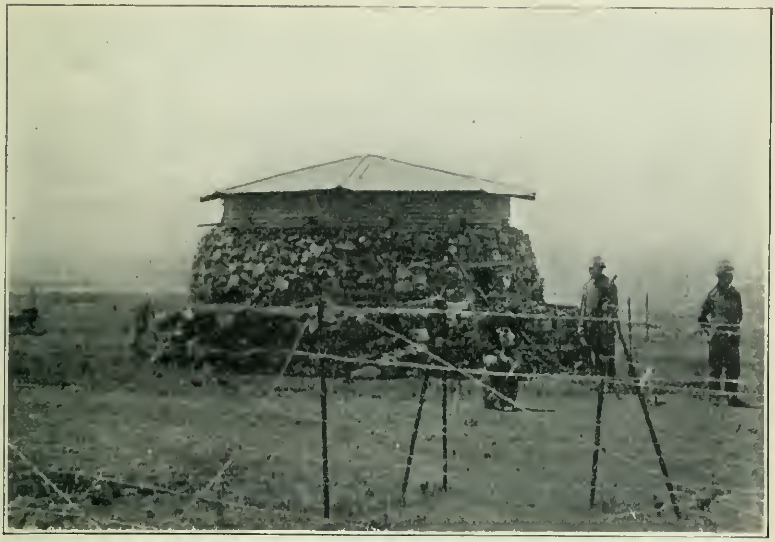


FIG. 1.—Corrugated iron Blockhouse with stone revetment (Elandsfontein).

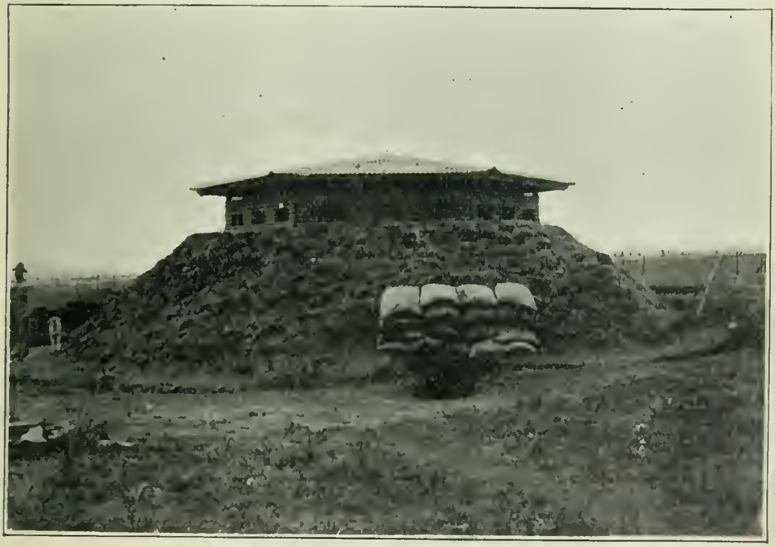


FIG. 2.—Corrugated iron Blockhouse with earth revetment (Kaalfontein).

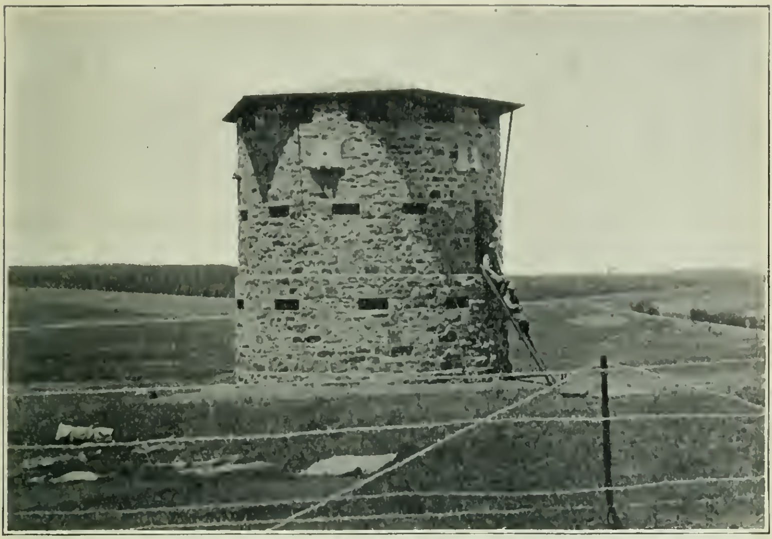


FIG. 1.—Masonry Blockhouse, 3 storied (between Kaalfontein and Zuurfontein).

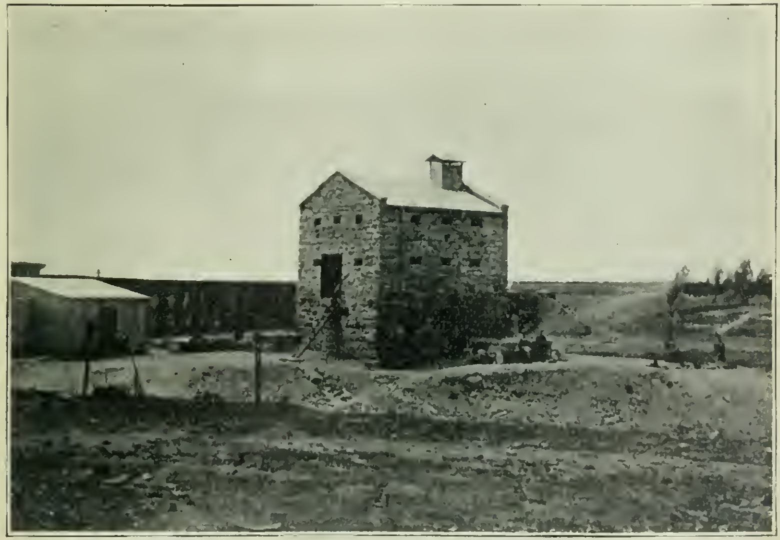


FIG. 2.—Masonry Blockhouse (at bridge head, Vereeniging).

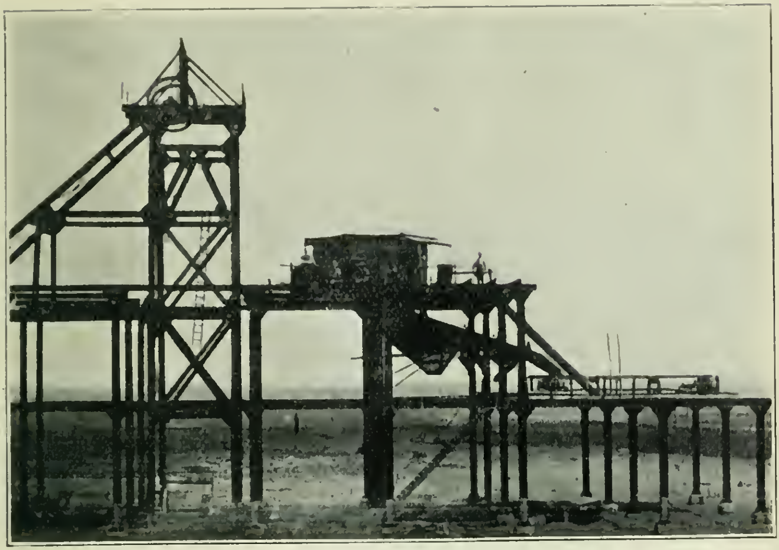


FIG. 1.—Corrugated iron Blockhouse (on mine-head gear, Schrapenrust, near Springs).

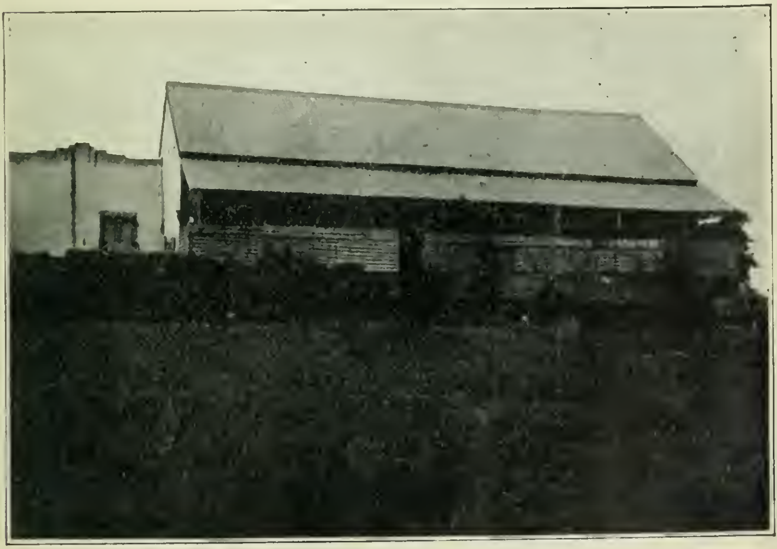


FIG. 2.—Defended farm.

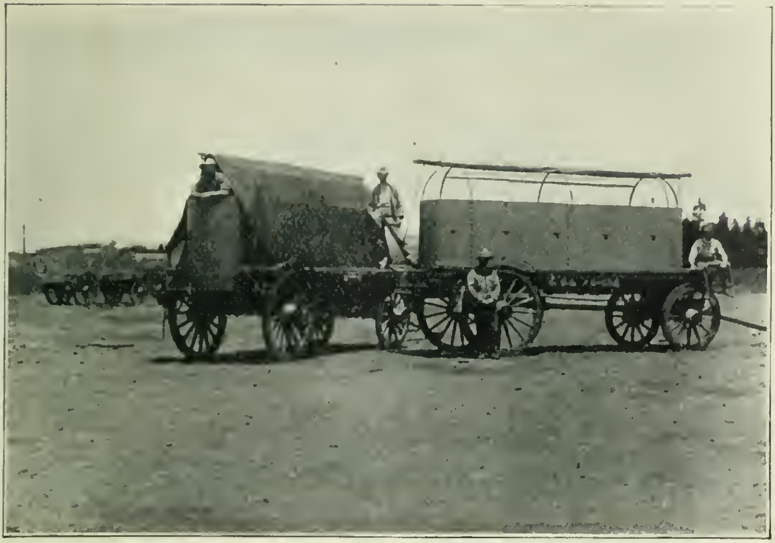


FIG. 1.—Ox-wagon Blockhouse (constructed by 47th Company, R.E.).

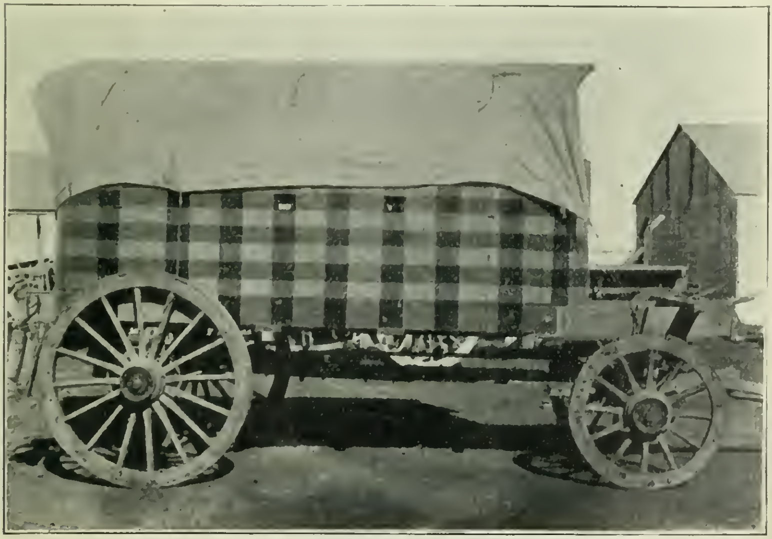
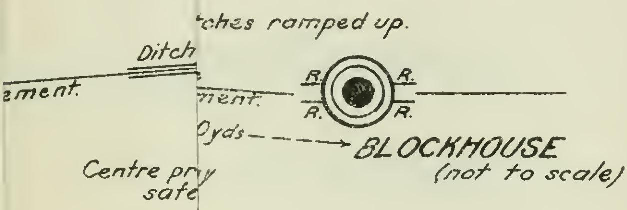


FIG. 2.—Ox-wagon Blockhouse, painted checkerwise.

PLATE VIII.

E OF FESES.——

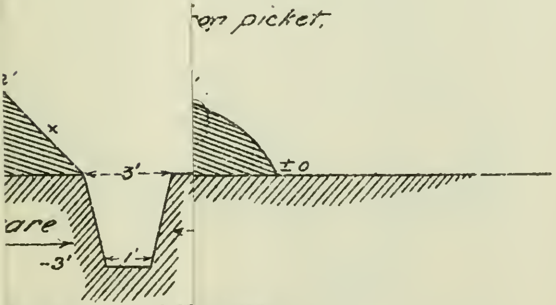


'led by wire ert 10 feet from edge of

e of sentry trers attempted to cross

de so that tre Fence with as nearly
· possible.

The top
plain

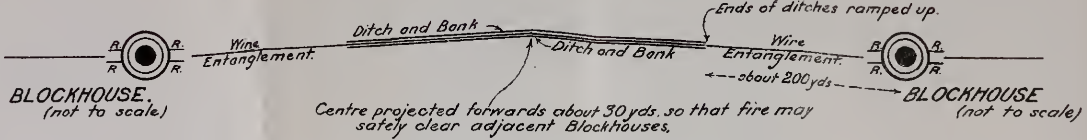


ROSS SETION.—

'tterly instelly finished before the other
likely crossin portions
employed f
ns reqired. Wiaccount of rocks.

PLATE VIII.

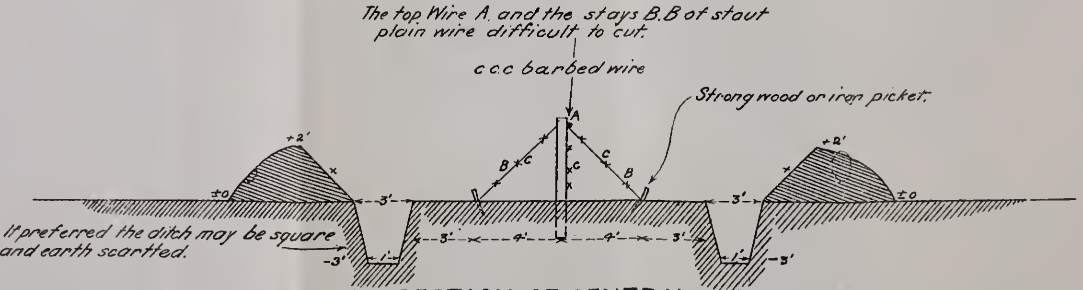
TYPE OF FENCING BETWEEN BLOCKHOUSES.



Centre projected forwards about 30yds. so that fire may safely clear adjacent Blockhouses.

Each blockhouse surrounded by wire entanglements and by sentry trench cut about 10 feet from edge of blockhouse.
R.R. rests for Rifles on edge of sentry trench, in which rifles could be laid when Boers attempted to cross at night.
The rests carefully made so that the fire could sweep the sides of the Wire Fence with as nearly correct elevation as possible.

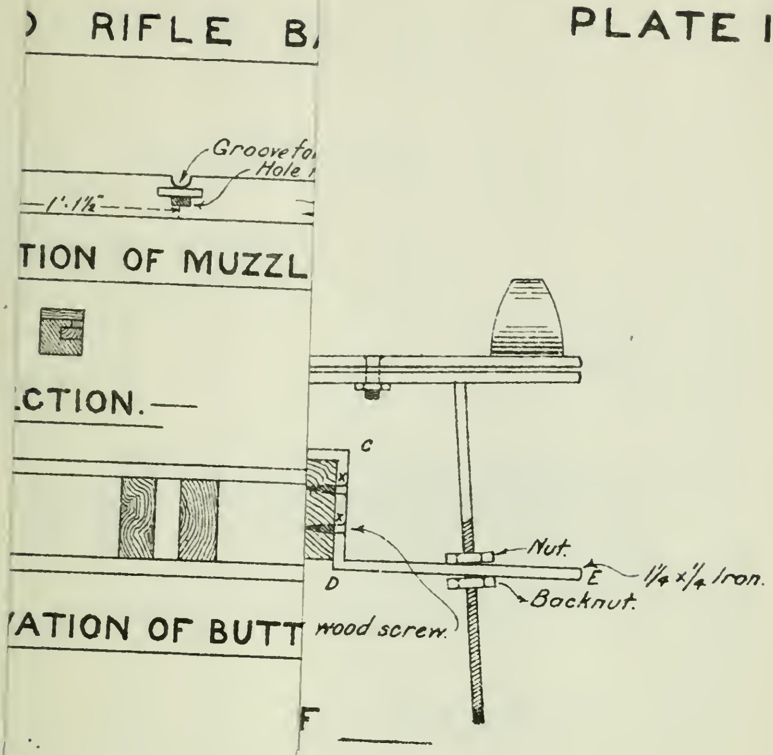
PLAN


The top Wire A. and the stays B.B of stout plain wire difficult to cut.
c.c.c barbed wire
Strong wood or iron picket.
A
B
C
B
C
C
+2'
±0
3'
-3'
1'
3'
4'
4'
3'
3'
1'
-3'
+2'
±0
If preferred the ditch may be square and earth scartted.

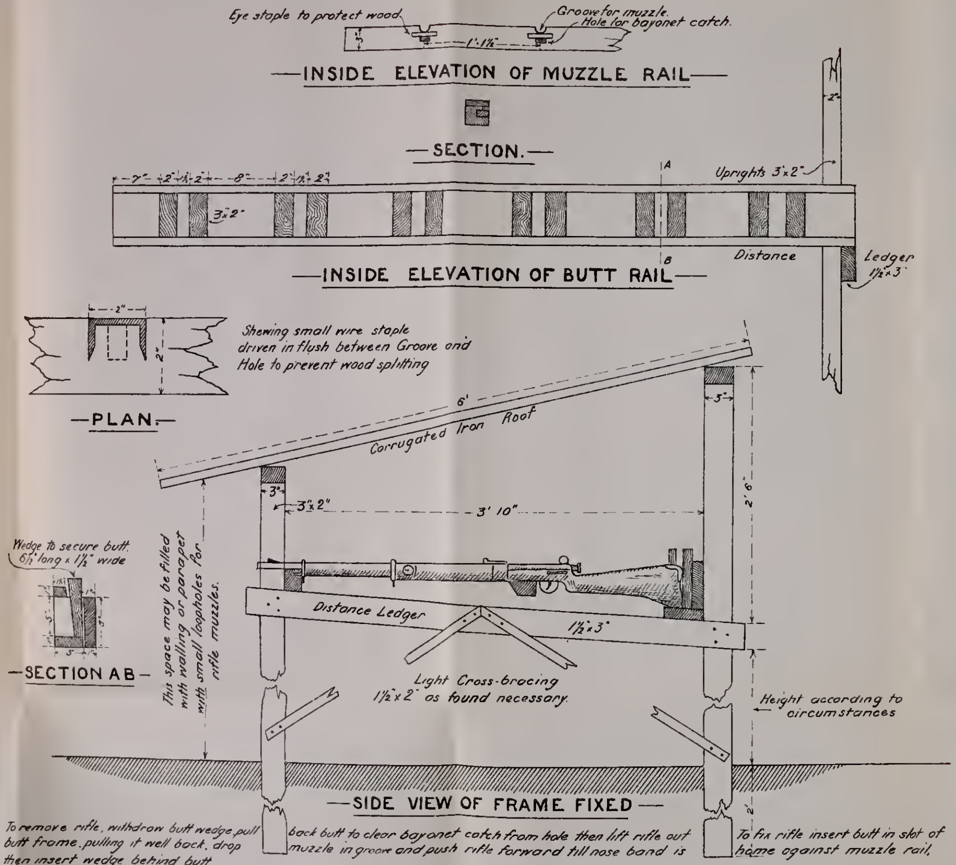
CROSS SECTION OF CENTRAL OBSTRUCTION.

A single deep wide ditch used latterly instead of two small ones. One ditch generally finished before the other commenced, except at tracks or likely crossings when both finished before collateral portions
Garrisons of blockhouses are to be employed for 3 hours daily on this work.
Flare Lights or Spring Guns fixed as regired. Walls built where digging impossible on account of rocks.

PLATE IX.


RIFLE BA
Groove fo
Hole
1'-1½"
TION OF MUZZL
CTION.
C
x
x
D
Nut.
E
1/4 x 1/4 Iron.
Backnut.
wood screw.
VATION OF BUTT
F

TYPE OF FIXED RIFLE BATTERY.


Eye staple to protect wood
Groove for muzzle.
Hole for bayonet catch.
1'·1½"
3"
Shewing small wire staple driven in flush between Groove and Hole to prevent wood splitting
2"
7"
2"
1½"
2"
8"
2"
1½"
2"
3"x2"
A
B
Uprights 3"x2"
Distance
Ledger 1½"x3"
6'
Corrugated Iron Roof
3"
3"x2"
3' 10"
2' 6"
Wedge to secure butt 6½" long x 1½" wide
This space may be filled with walling or parapet with small loopholes for rifle muzzles.
Distance Ledger
1½"x3"
Light Cross-bracing 1½"x2" as found necessary.
Height according to circumstances
2'

INSIDE ELEVATION OF MUZZLE RAIL

SECTION.

INSIDE ELEVATION OF BUTT RAIL

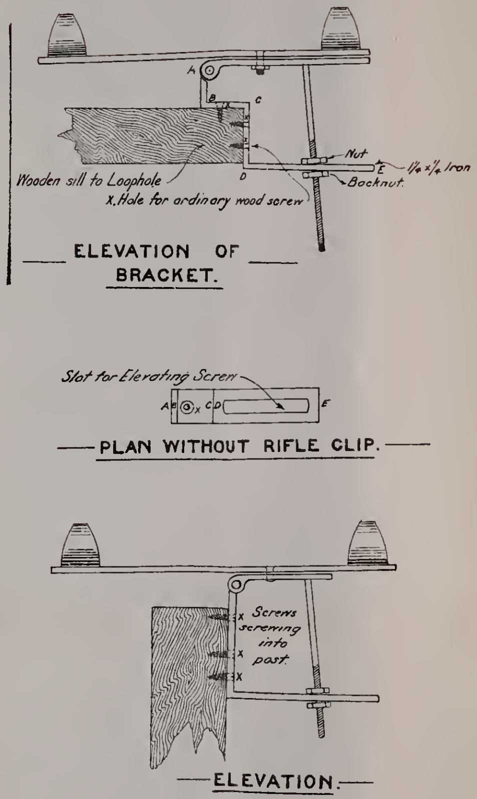
PLAN.

SECTION AB

SIDE VIEW OF FRAME FIXED

To remove rifle, withdraw butt wedge, pull back butt to clear bayonet catch from hole then lift rifle out. To fix rifle insert butt in slot of
butt frame, pulling it well back, drop muzzle in groove and push rifle forward till nose band is home against muzzle rail,
then insert wedge behind butt

When erecting, first secure buttrail to uprights at the convenient height at right-angles to line of fire. Then plant uprights at proper distance. Then holding Muzzle Rail against uprights, put in a rifle, and adjust aim and range accurately, raising either end of muzzle rail as may be necessary to obtain longer ranges.
Then nail muzzle rail to uprights and fix distance ledgers and crossbraces if required.



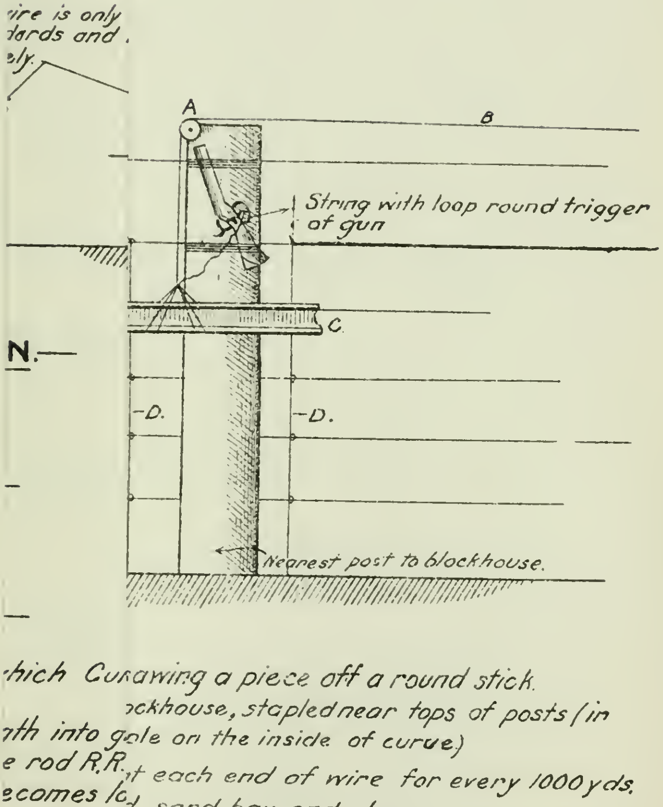
ELEVATION OF BRACKET.

PLAN WITHOUT RIFLE CLIP.

ELEVATION.

ALTERNATIVE TYPE OF RIFLE REST

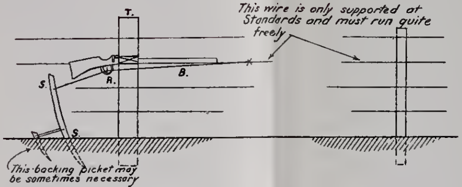
PLATE X.


ire is only
dards and
ely.
A
B
String with loop round trigger of gun
C.
N.—
–D.
–D.
Nearest post to blockhouse.

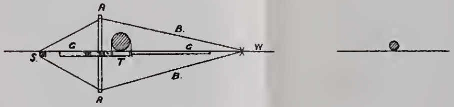
hich Cusawing a piece off a round stick.
ockhouse, stapled near tops of posts (in
th into gole on the inside of curve)
e rod R.R. t each end of wire for every 1000 yds.
ecomes lo d sand-bag and stones.
of Spanis rail and fence wires to prevent end
the trigge and resting on fence.
ed. other end, both guns are fired when
substitutween.

PLATE X.

TYPES OF ALARM GUNS.


T.
This wire is only supported at Standards and must run quite freely
S.
R.
B.
S.
This backing picket may be sometimes necessary

ELEVATION.



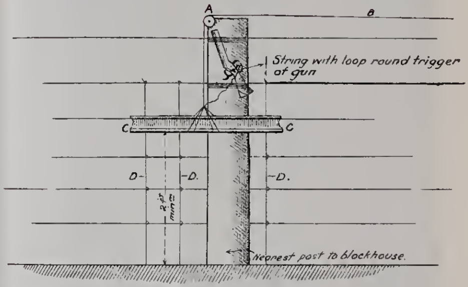
PLAN

T, Telegraph or other stout post, to which Gun, G.G. is secrely lashed

S, Standard, driven about half its length into ground, acting as spring to fire Gun by means of the rod R.R. which presses back the trigger when the bridle B.B becomes loose on wire W being cut

This bridle is fixed to W, and by means of Spanish Windlass is twisted so as to keep R from pressing the trigger till W is cut, when the tension on spring S is released.

A cart spring has in many cases been substituted for S, with a modified plan of fixing.


A
B
String with loop round trigger of gun
C
C
D-
-D.
-D.
2 ft min
Nearest post to blockhouse.

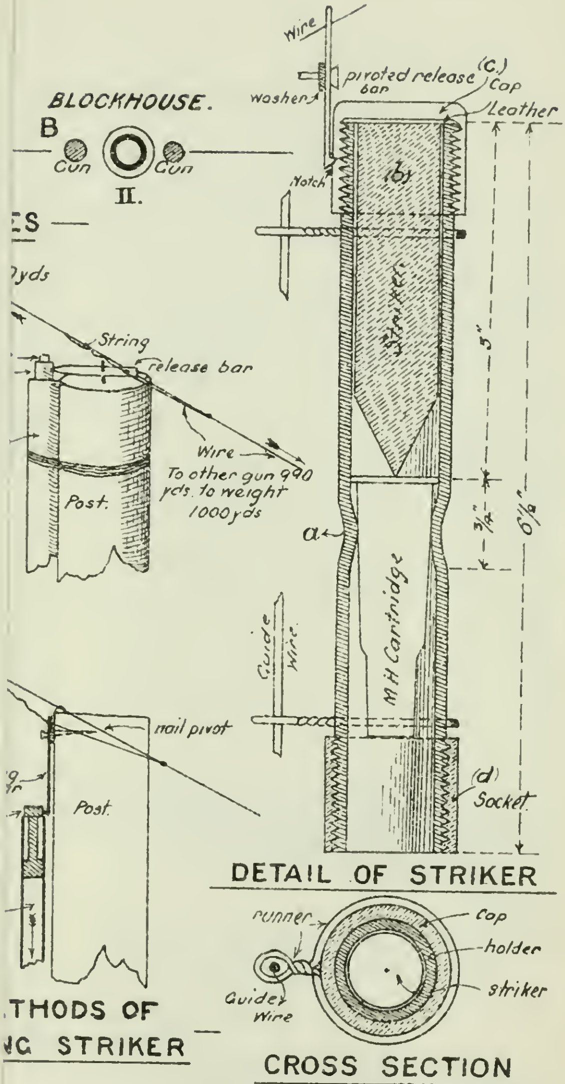
A, Pulley or roller, made by sawing a piece off a round stick

B, Continuous wire to next blockhouse, stapled near tops of posts (in going round a curve-staple on the inside of curve)

C. 60 lbs of railway metal at each end of wire for every 1000 yds. or tin of stones or tarred sand-bag and stones.

D. Upright wires between rail and fence wires to prevent end of rail swinging between and resting on fence.

NB Same arrangement at other end, both guns are fired when wire is cut anywhere between.



THODS OF
NG STRIKER

DETAIL OF STRIKER

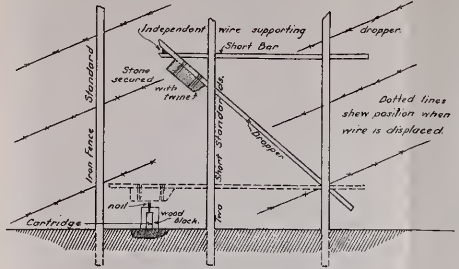
CROSS SECTION

ther pad. (d) W.I. socket to equalise thickness

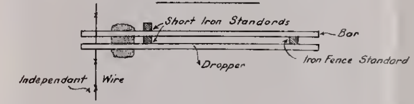
in a guiding tube, or fixed in the large
to post

nent.

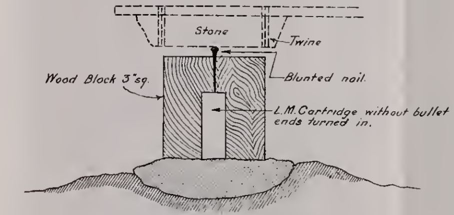
—TYPES OF ALARM SIGNALS.—



—ELEVATION—

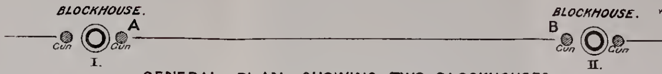


—PLAN—

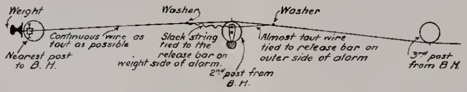


— DETAIL OF CARTRIDGE, ETC. —

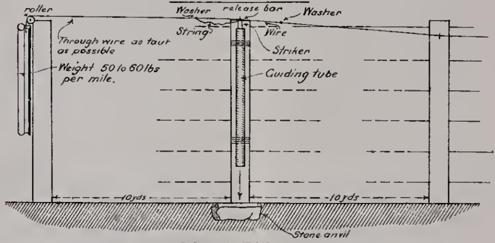
Note.
This Alarm can be fixed either inside or outside wire entanglement.



— GENERAL PLAN SHOWING TWO BLOCKHOUSES —


Weight
Washer
Washer
Continuous wire as taut as possible
Slack string tied to the release bar on weight side of alarm.
Almost taut wire tied to release bar on outer side of alarm
Nearest post to B.H.
2nd post from B.H.
3rd post from B.H.

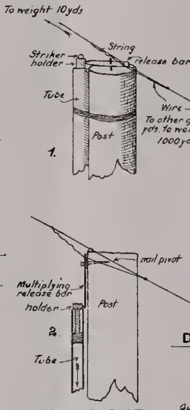
—DETAIL PLAN—



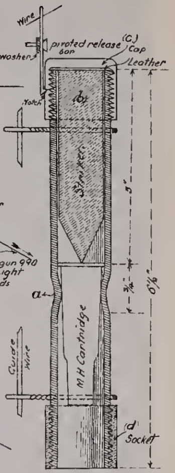
—ELEVATION—

When the continous wire anywhere between A and B is (i) cut or (ii) charged into in the dark or (iii) forcibly raised to pass under, the alarms at both A and B are fired and sentries at both I and II are warned.

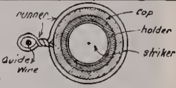
The thin string tied to release bar acts in case of (i) and the taut wire on other side of bar acts in (ii) and (iii).



— METHODS OF FIXING STRIKER —



DETAIL OF STRIKER



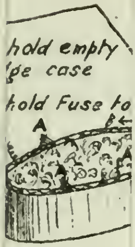
CROSS SECTION

In detail of striker (a) is a piece of ¾" W I pipe, with a waist pinched near centre to prevent cartridge falling through; (b) piece of round steel, worked smooth, and filed to point in true centre of one end (C) W I stop cap with leather pad. (d) W.I. socket to equalise thickness of ends

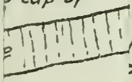
The release bar may be fixed horizontal or vertical, as shown. The striker may be in a guiding tube, or fixed in the large rings of ∞ wire runners, sliding in their small rings on vertical wire fixed to post

PLATE XII.

T



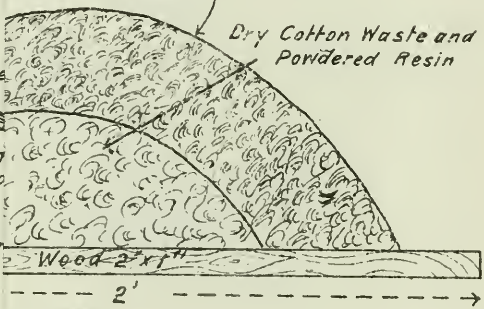
re bared
Cap of



"A"

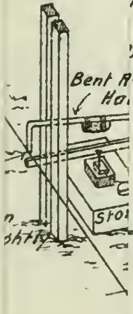
small bun
trands of Co

e covered
er inflamm



uncotton
ner

ject 3/8" — The Cotton Waste to be
und to the wood with twine



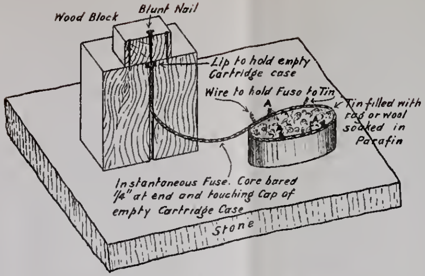
HAMMER
SET

ARE WITH FRICTION TUBE

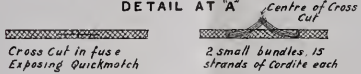
ARM

PLATE XII.

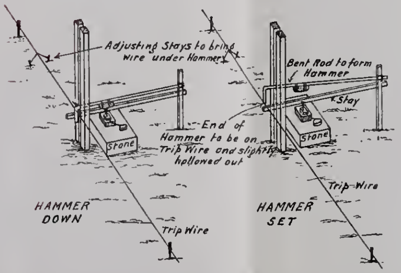
TYPES OF ALARM FLARES


Wood Block
Blunt Nail
Lip to hold empty Cartridge case
Wire to hold Fuse to Tin
A
Tin filled with rag or wool soaked in Parafin
Instantaneous Fuse. Core bored ¼" at end and touching Cap of empty Cartridge Case
Stone

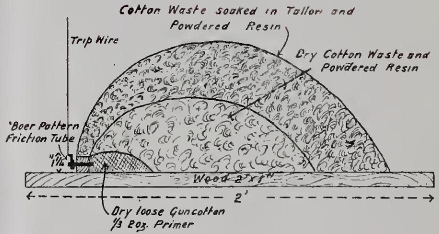
DETAIL AT "A"


Centre of Cross Cut
Cross Cut in fuse Exposing Quickmatch
2 small bundles, 15 strands of Cordite each

In Wet Weather Flare can be covered by a tarred Mealie Bag or other inflammable Material


Adjusting Stays to bring wire under Hammer
Bent Rod to form Hammer
Stay
End of Hammer to be on Trip Wire and slightly hollowed out
Stone
Stone
Trip Wire
Trip Wire
HAMMER DOWN
HAMMER SET

MOFFIT'S ALARM

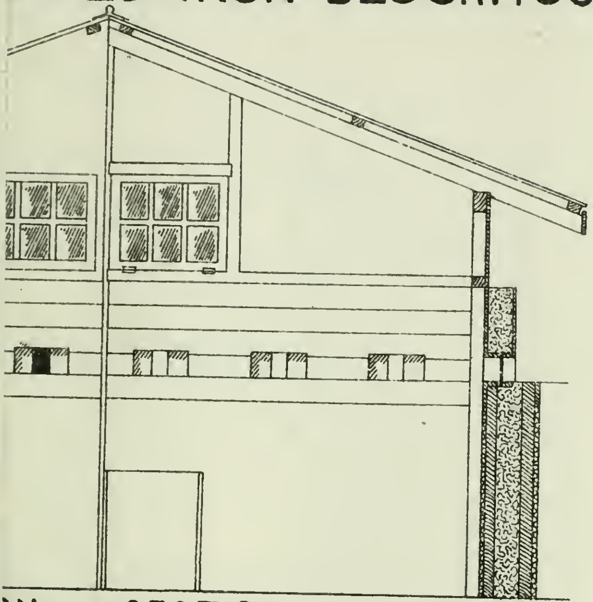

Cotton Waste soaked in Tallow and Powdered Resin
Trip Wire
Dry Cotton Waste and Powdered Resin
'Boer Pattern Friction Tube
1¼"
Wood 2"x1"
2'
Dry loose Guncotton ⅓ 2oz. Primer

Tube to project ⅜" — The Cotton Waste to be bound to the wood with twine

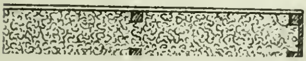
AUTOMATIC FLARE WITH FRICTION TUBE

'YPE OF PLATE XIII.

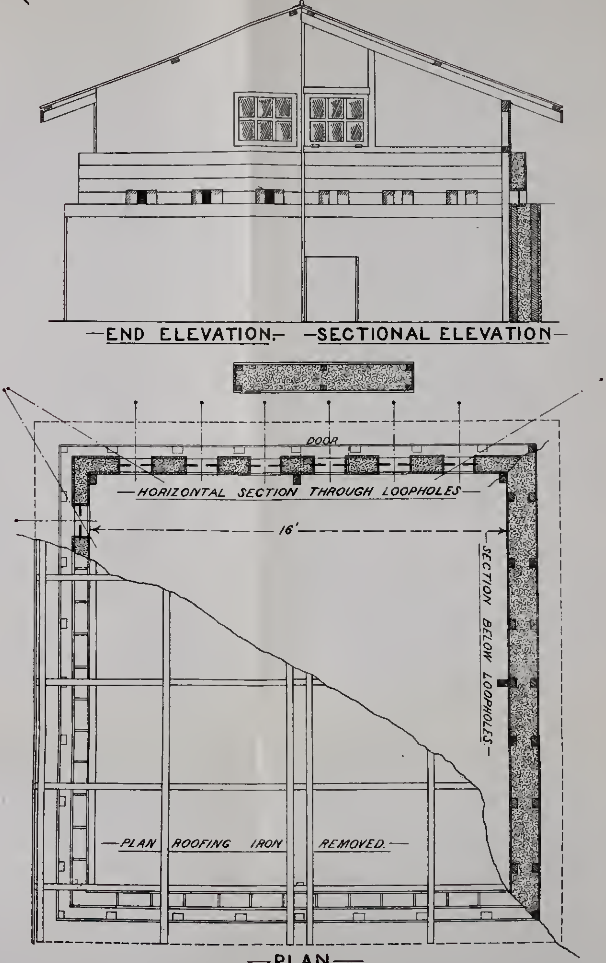
ATED IRON BLOCKHOUSE.



)N.— —SECTIONAL ELEVATION—



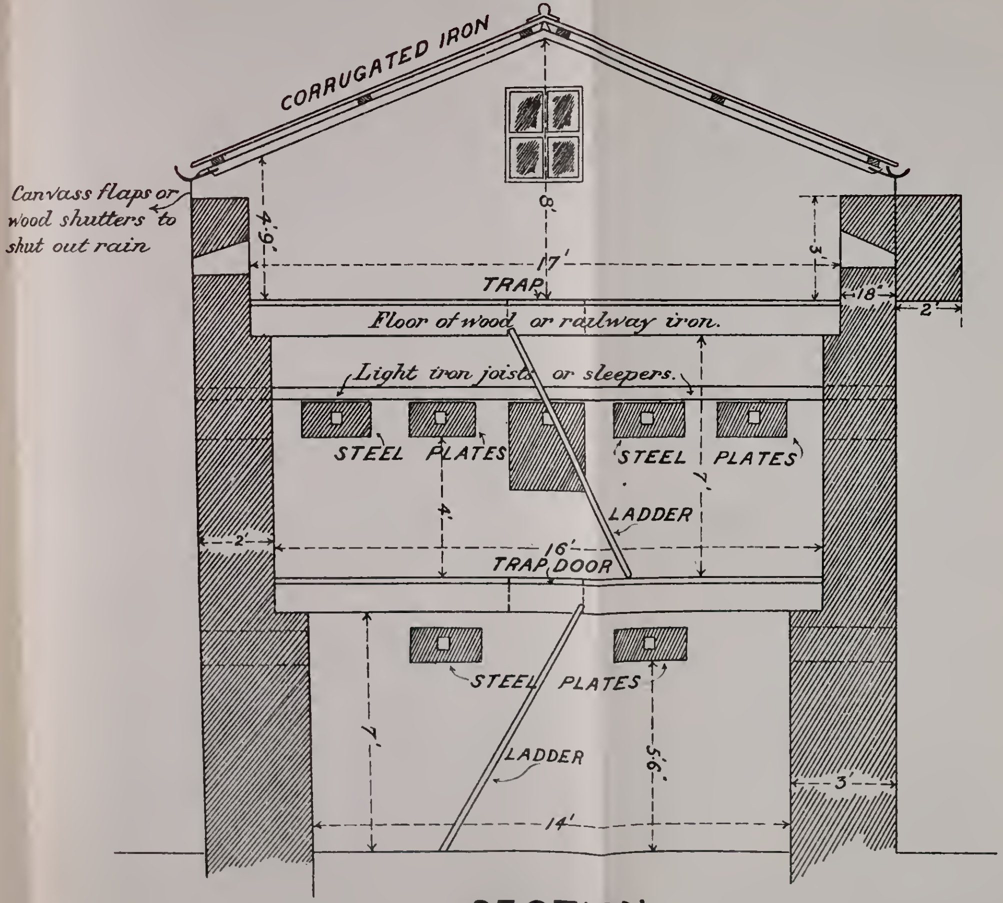
TYPE OF SQUARE CORRUGATED IRON BLOCKHOUSE.


—END ELEVATION.—
—SECTIONAL ELEVATION—
DOOR
—HORIZONTAL SECTION THROUGH LOOPHOLES—
16'
—SECTION BELOW LOOPHOLES.—
—PLAN ROOFING IRON REMOVED.—

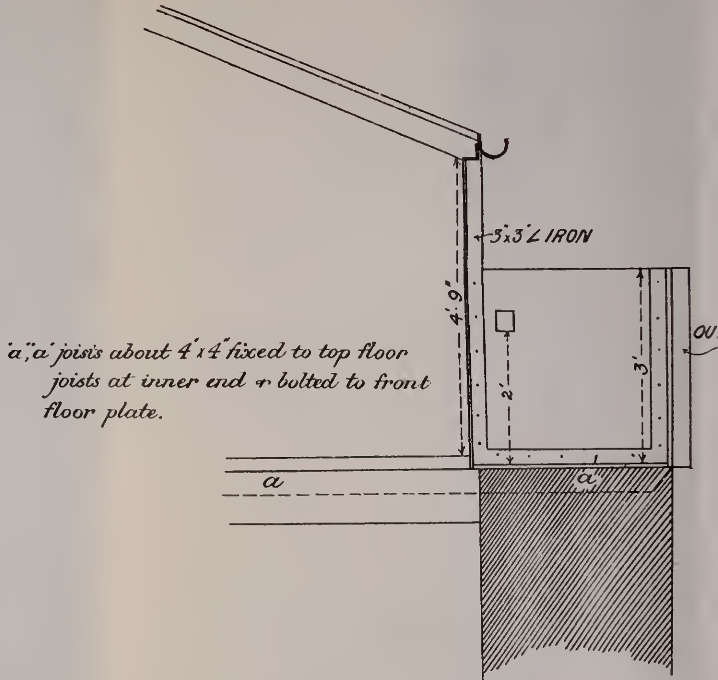
—PLAN—

Scale, 1inch = 4feet.

TYPE OF
TWO-STORY MASONRY BLOCKH



SECTION


3"x3" L IRON
4'9"
2'
3'
"a","a" joists about 4"x4" fixed to top floor joists at inner end & bolted to front floor plate.
a
a"
OU

SECTION ON A,B.

THE PLATES USED IN CONSTRUCTION OF GALLERIES AND LOOPHOLES
3/8" HARDENED STEEL.

PLATES FOR GALLERIES WERE 6"x18" EXCEPT THE END PLATES WH
3"x3".

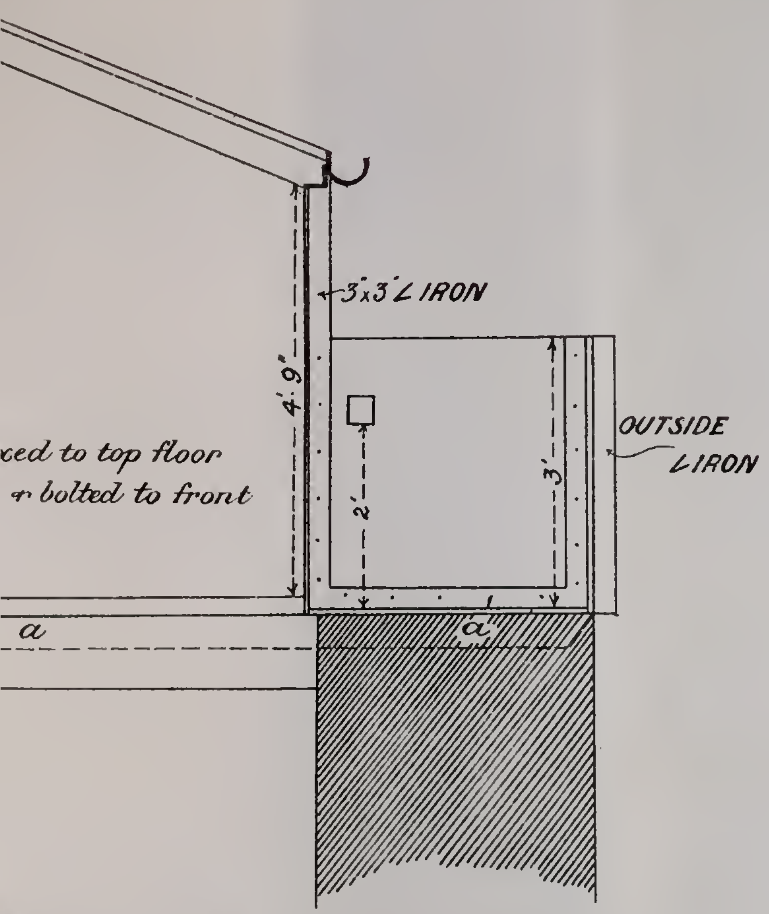
THE BOTTOMS AND FRONTS OF THE GALLERIES WERE MADE WIT
PLATES EACH.

ALL LOOPHOLES WERE 4"x3" OR 4" CIRCULAR.

PLAN OF GALLERY

TYPE OF
Y MASONRY BLOCKHOUSE.

PLATE XIV.



SECTION ON A,B.

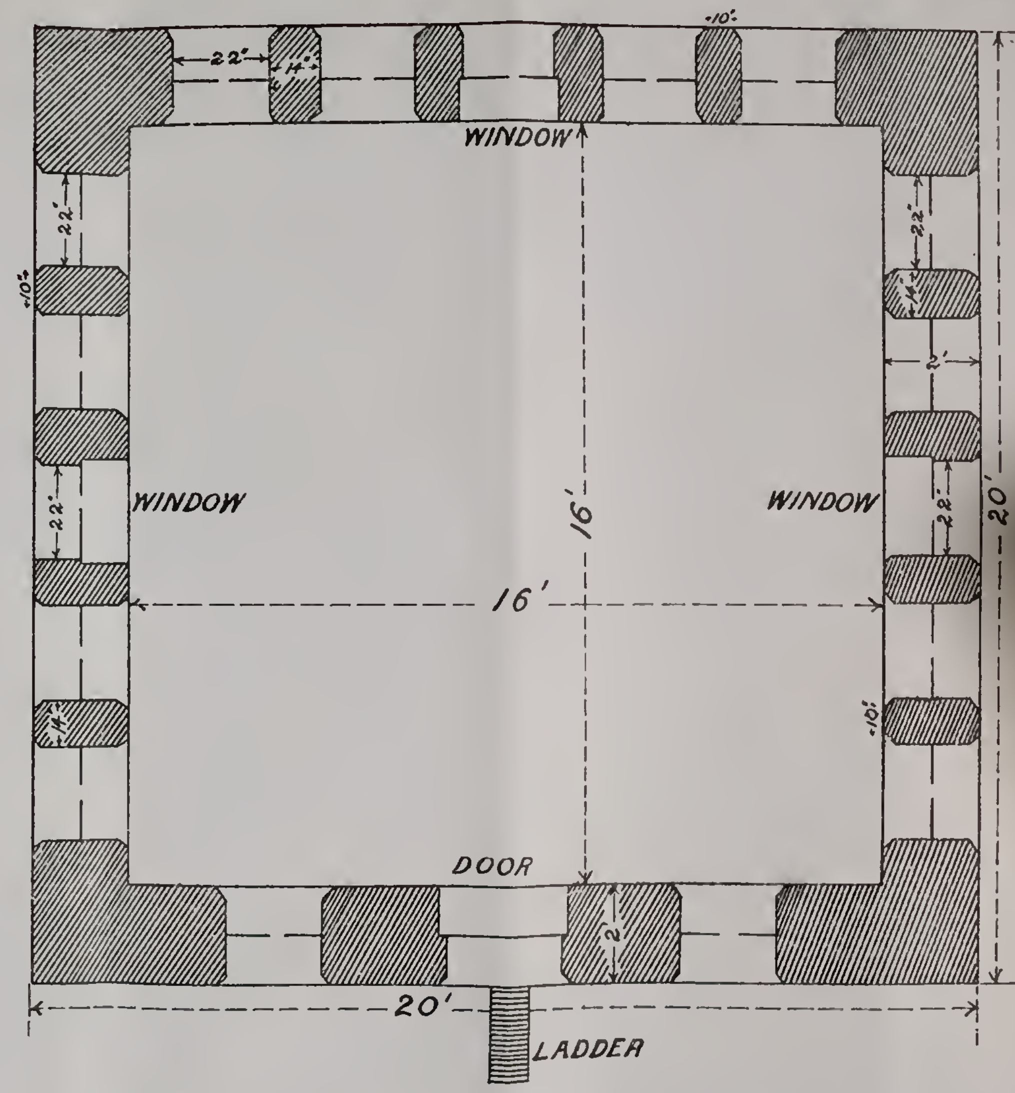
ONSTRUCTION OF GALLERIES AND LOOPHOLES WERE OF
EL.

S WERE 6"x18" EXCEPT THE END PLATES WHICH WERE

FRONTS OF THE GALLERIES WERE MADE WITH TWO

E 4"x3" OR 4" CIRCULAR.

AN OF GALLERY



PLAN OF WALLS AT LEVEL OF LOOPHOLES, FIRST FLOOR.

—SECTION ON A,B.—

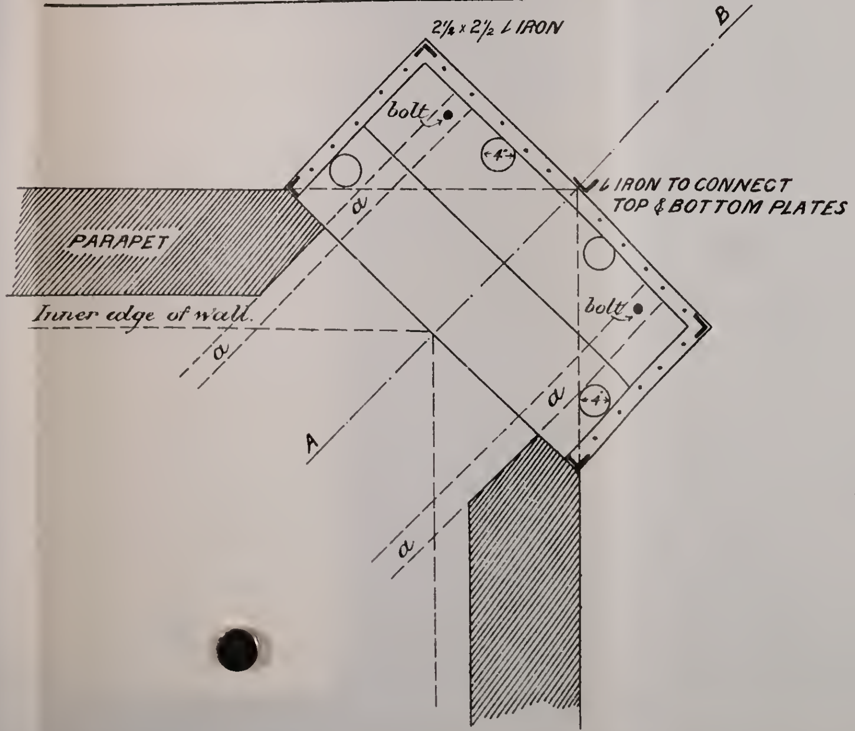
THE PLATES USED IN CONSTRUCTION OF GALLERIES AND LOOPHOLES WERE OF $\frac{3}{8}$" HARDENED STEEL.

PLATES FOR GALLERIES WERE 6'x18" EXCEPT THE END PLATES WHICH WERE 3"x3".

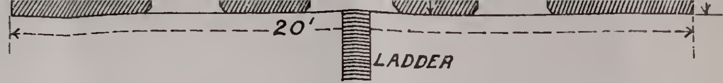
THE BOTTOMS AND FRONTS OF THE GALLERIES WERE MADE WITH TWO PLATES EACH.

ALL LOOPHOLES WERE 4"x3" OR 4" CIRCULAR.

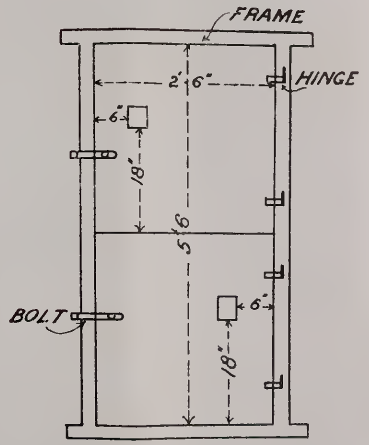
—PLAN OF GALLERY—



TANK
in ground.

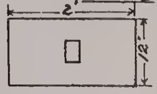


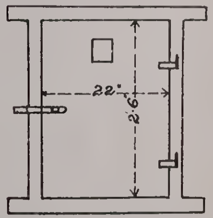
PLAN OF WALLS AT LEVEL OF LOOPHOLES, FIRST FLOOR.



DOOR IN TWO LEAVES, HUNG IN W. I. FRAME.

—LOOPHOLE PLATE—

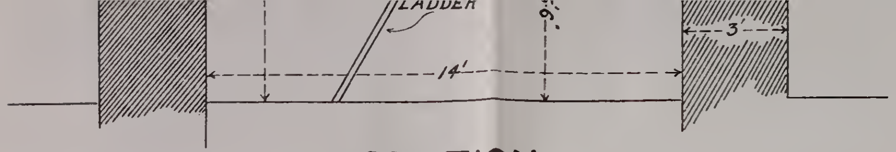




—SHUTTER IN W I FRAME—

SCALE, 1 INCH – 4 FEET.

DETAILS, 1 INCH – 2 FEET.



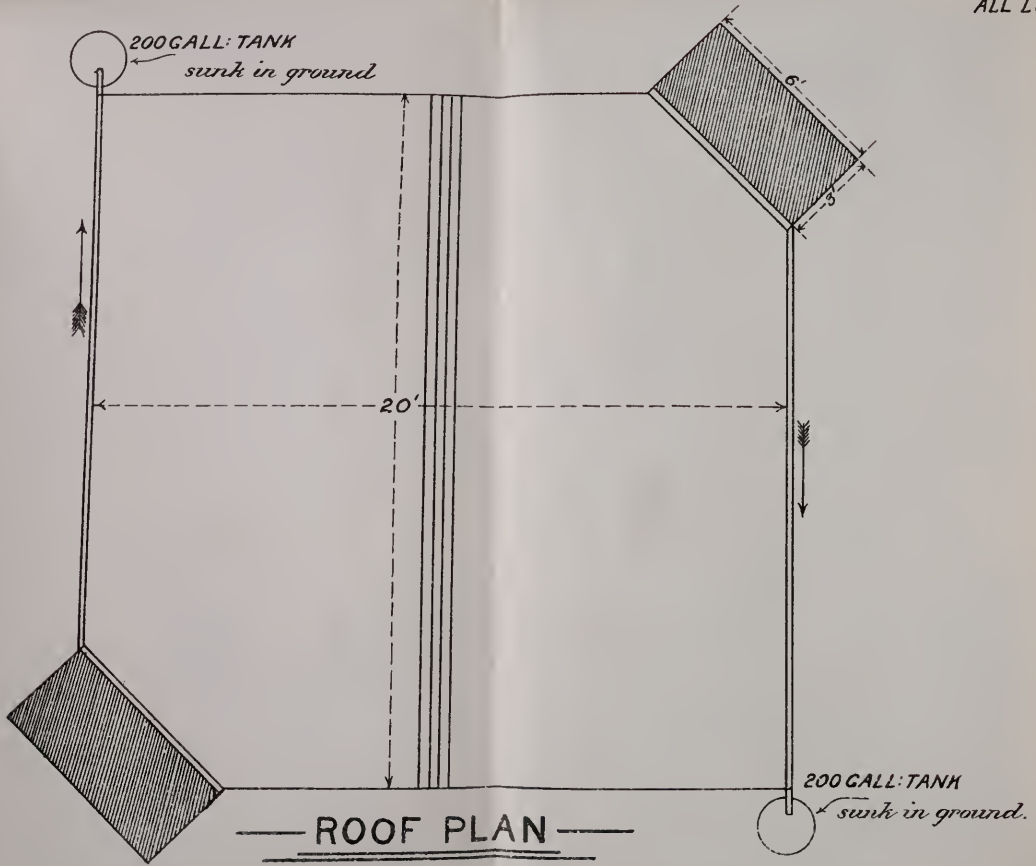
—SECTION—

THE PLATES USED IN CONSTRUCTION OF GALLERIES AND LOOPHOLES WERE OF 3/8" HARDENED STEEL.

PLATES FOR GALLERIES WERE 6'x18" EXCEPT THE END PLATES WHICH WERE 3"x3".

THE BOTTOMS AND FRONTS OF THE GALLERIES WERE MADE WITH TWO PLATES EACH.

ALL LOOPHOLES WERE 4"x3" OR 4" CIRCULAR.



—ROOF PLAN—

—PLAN OF GALLERY—

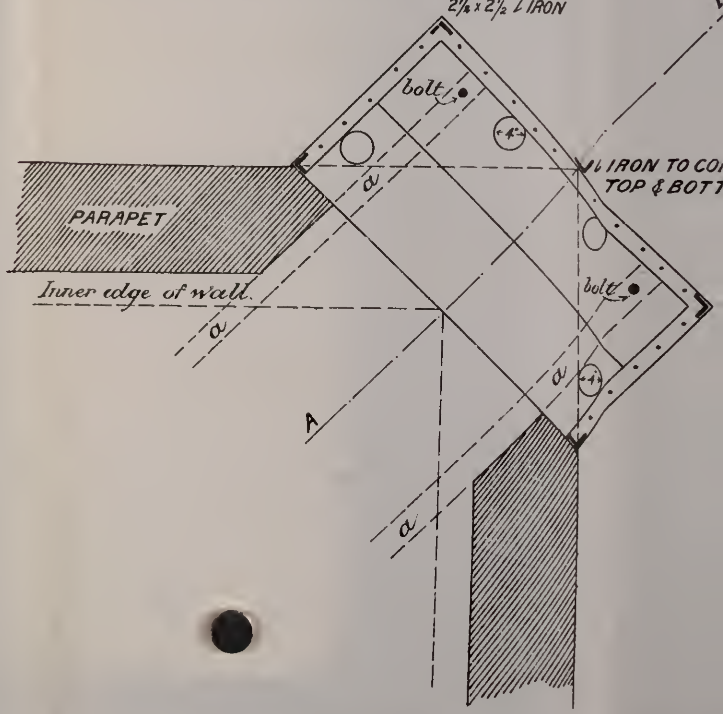
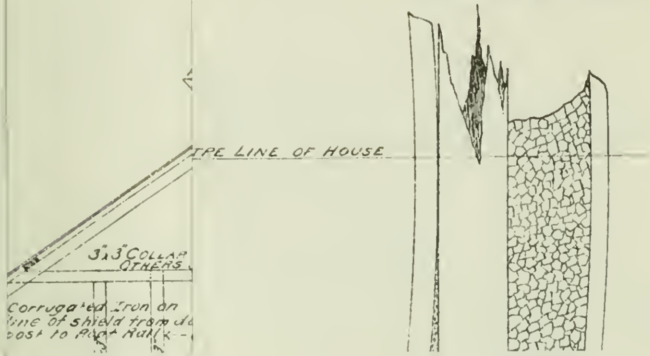
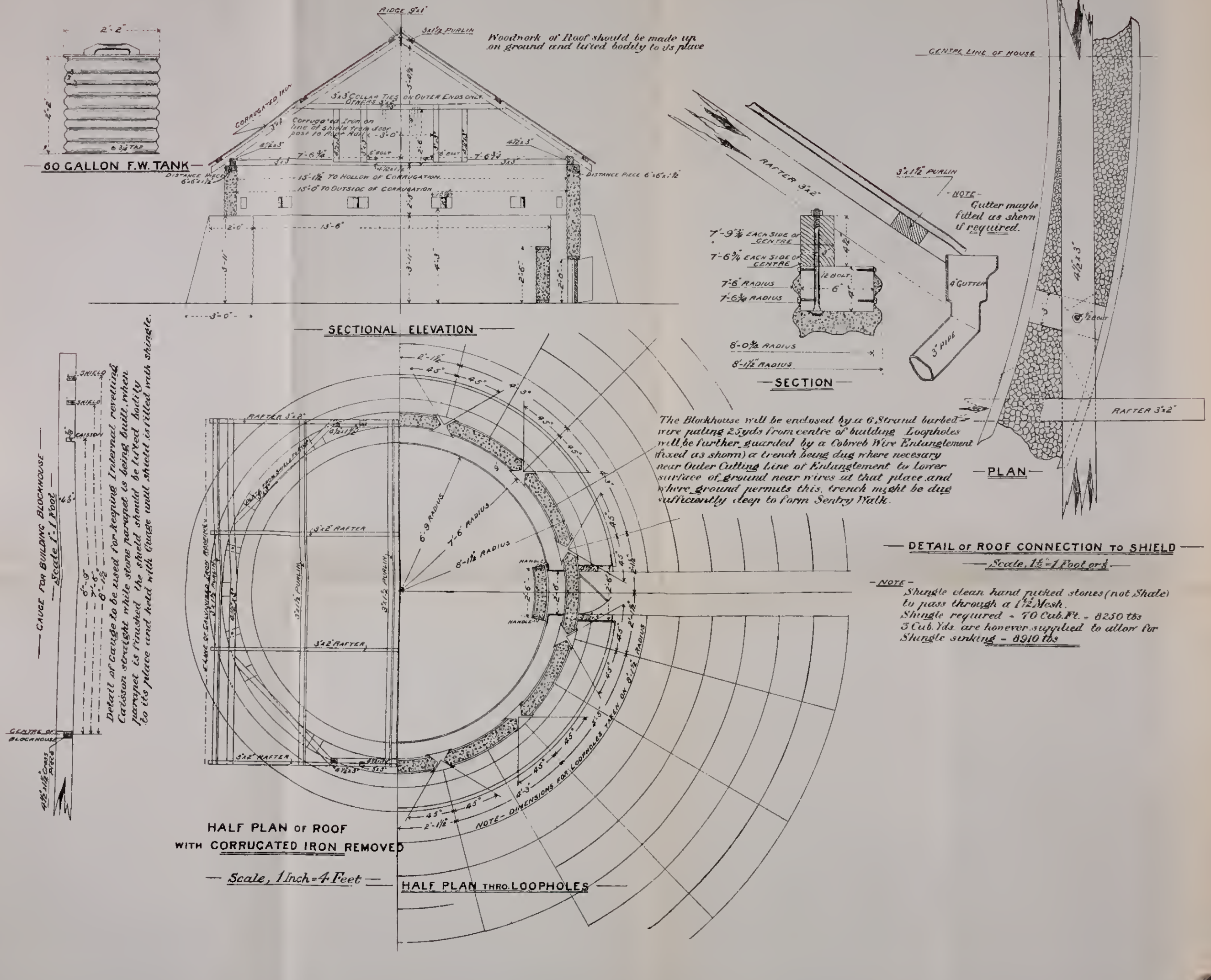


PLATE XV.


TPE LINE OF HOUSE
3"x3" COLLAR
OTHERS
Corrugated Iron on
line of shield from d
post to Roof Rail

TYPE OF
CIRCULAR CORRUGATED IRON BLOCKHOUSE

PLATE XV.



—60 GALLON F.W. TANK—

—SECTIONAL ELEVATION—

Woodnork of Roof should be made up on ground and lifted bodily to its place

—SECTION—

—PLAN—

—DETAIL OF ROOF CONNECTION TO SHIELD—

—*Scale, 1½"=1 Foot or ⅛*—

-NOTE- *Gutter may be fitted as shewn if required.*

The Blockhouse will be enclosed by a 6 Strand barbed wire paling 25yds from centre of building. Loopholes will be further guarded by a Cobweb Wire Entanglement (fixed as shown) a trench being dug where necesary near Outer Cutting Line of Entanglement to lower surface of ground near wires at that place and where ground permits this, trench might be dug sufficiently deep to form Sentry Walk.

-NOTE-
Shingle clean hand picked stones (not Shale) to pass through a 1½" Mesh.
Shingle required - 70 Cub.Ft. - 8250 lbs
3 Cub. Yds. are however supplied to allow for Shingle sinking - 8910 lbs

— GAUGE FOR BUILDING BLOCKHOUSE —

— *Scale 1"-1 Foot* —

Detail of Gauge to be used for keeping Internal revetting Caisson straight while stone parapet is being built, when parapet is finished the shield should be lifted bodily to its place and held with Guage until shield is filled with shingle.

HALF PLAN OF ROOF
WITH CORRUGATED IRON REMOVED

— *Scale, 1 Inch=4 Feet* —

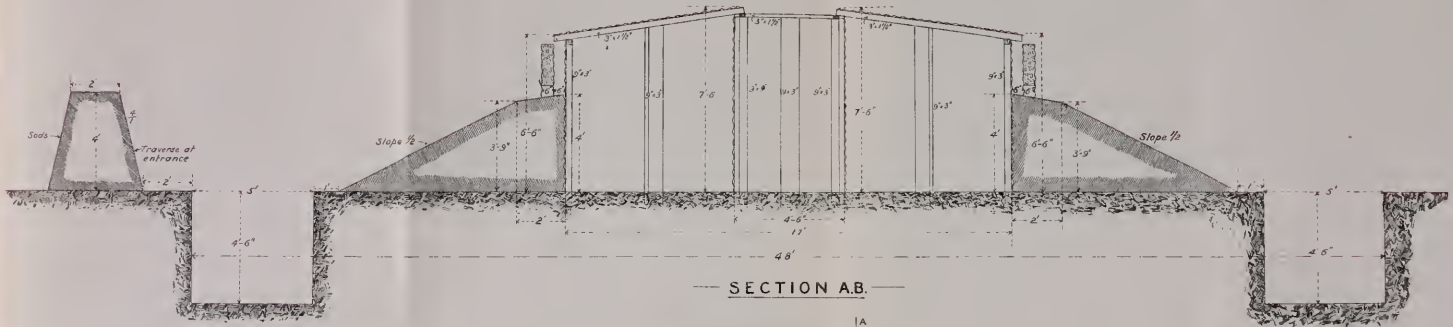
HALF PLAN THRO. LOOPHOLES

NOTE- DIMENSIONS FOR LOOPHOLES TAKEN ON 8'-1½" RADIUS

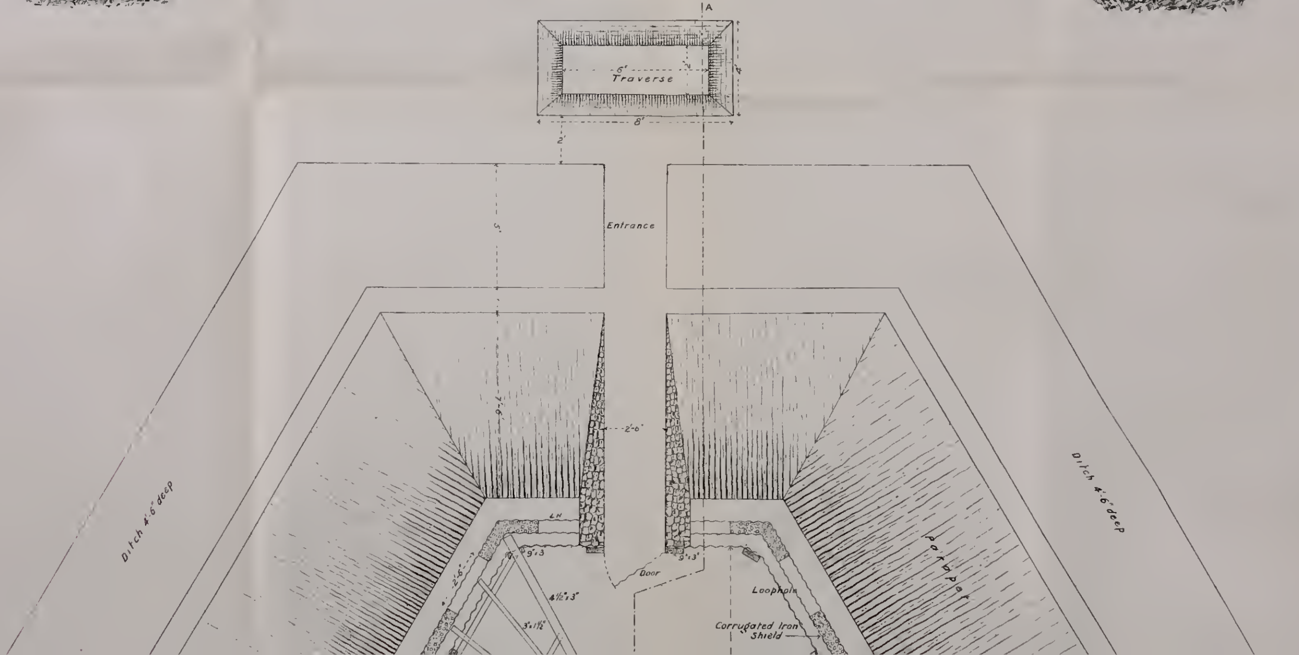
TYPE OF
RECTANGULAR CORRUGATED IRON BLOCKHOUSE

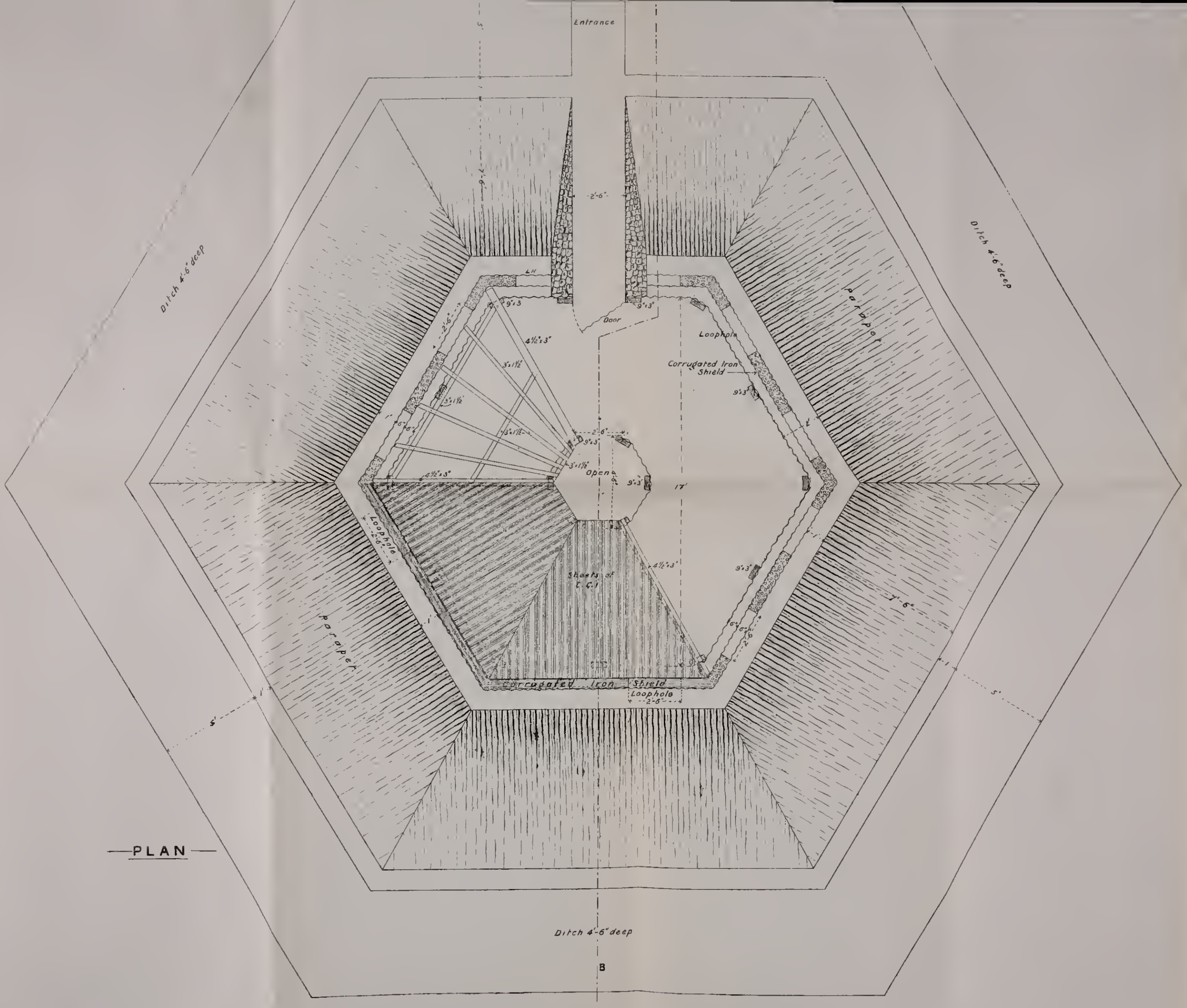
PLATE XVI

Scale, 1 Inch = 4 Feet.

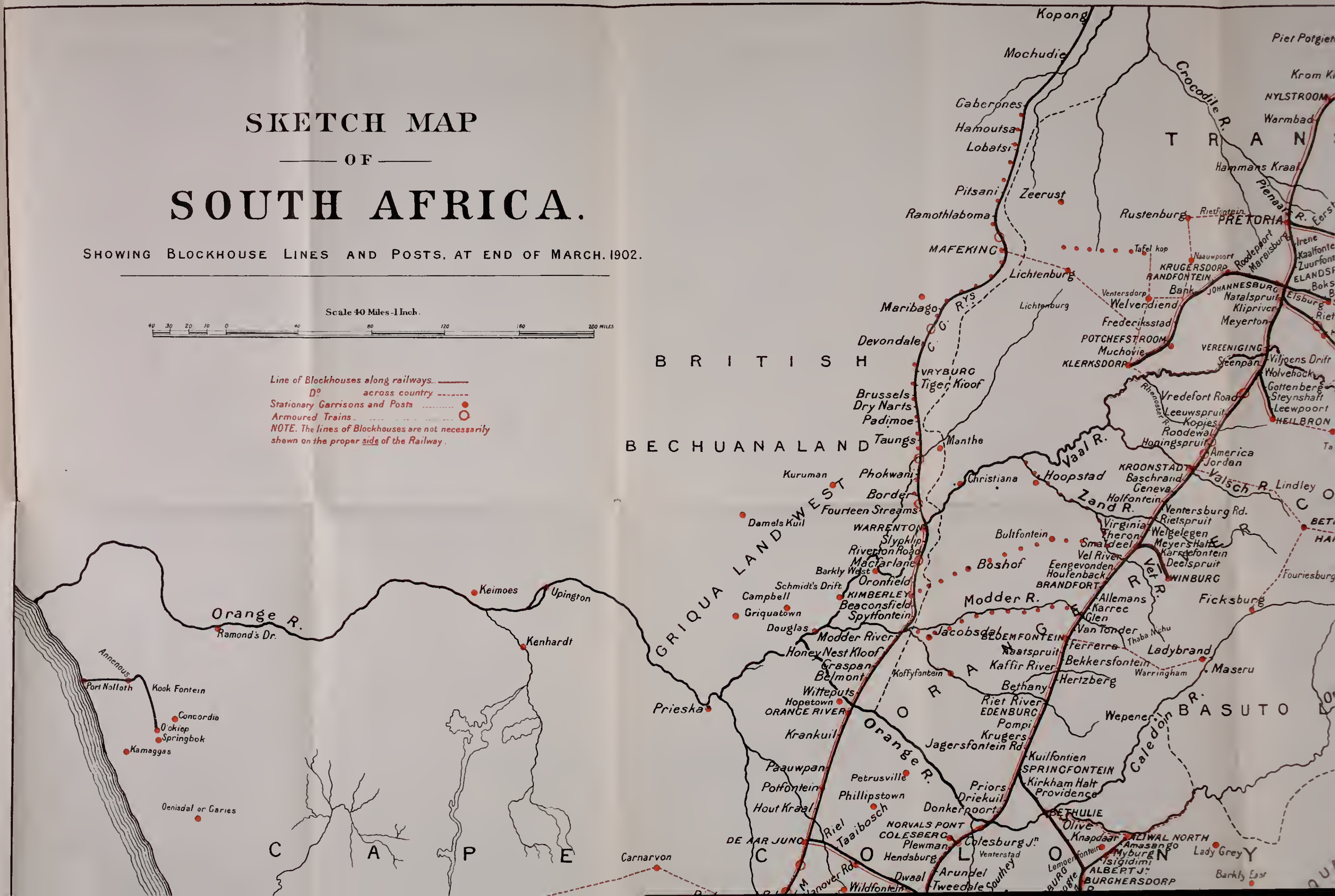


SECTION A.B.




Entrance
2'-6"
9'-6"
LH
9"x3
9"x3"
Door
4½"x3"
3"x1½"
3"x1½"
3"x1½"
3"x1½"
4½"x3"
2'-6"
6"
6"
1'
2'-6"
9"x3"
Open
9"x3"
17'
Loophole
Corrugated Iron Shield
9"x3"
2'
9"x3"
4½"x3"
Sheets of C.G.I
Loophole
2'-6"
Corrugated Iron Shield
Loophole
2'-6"
6"
6"
2'-6"
1'
1'-6"
1'
5'
5'
1'
parapet
parapet
Ditch 4'-6" deep
Ditch 4'-6" deep
Ditch 4'-6" deep
B

—PLAN—



SKETCH MAP

OF

SOUTH AFRICA.

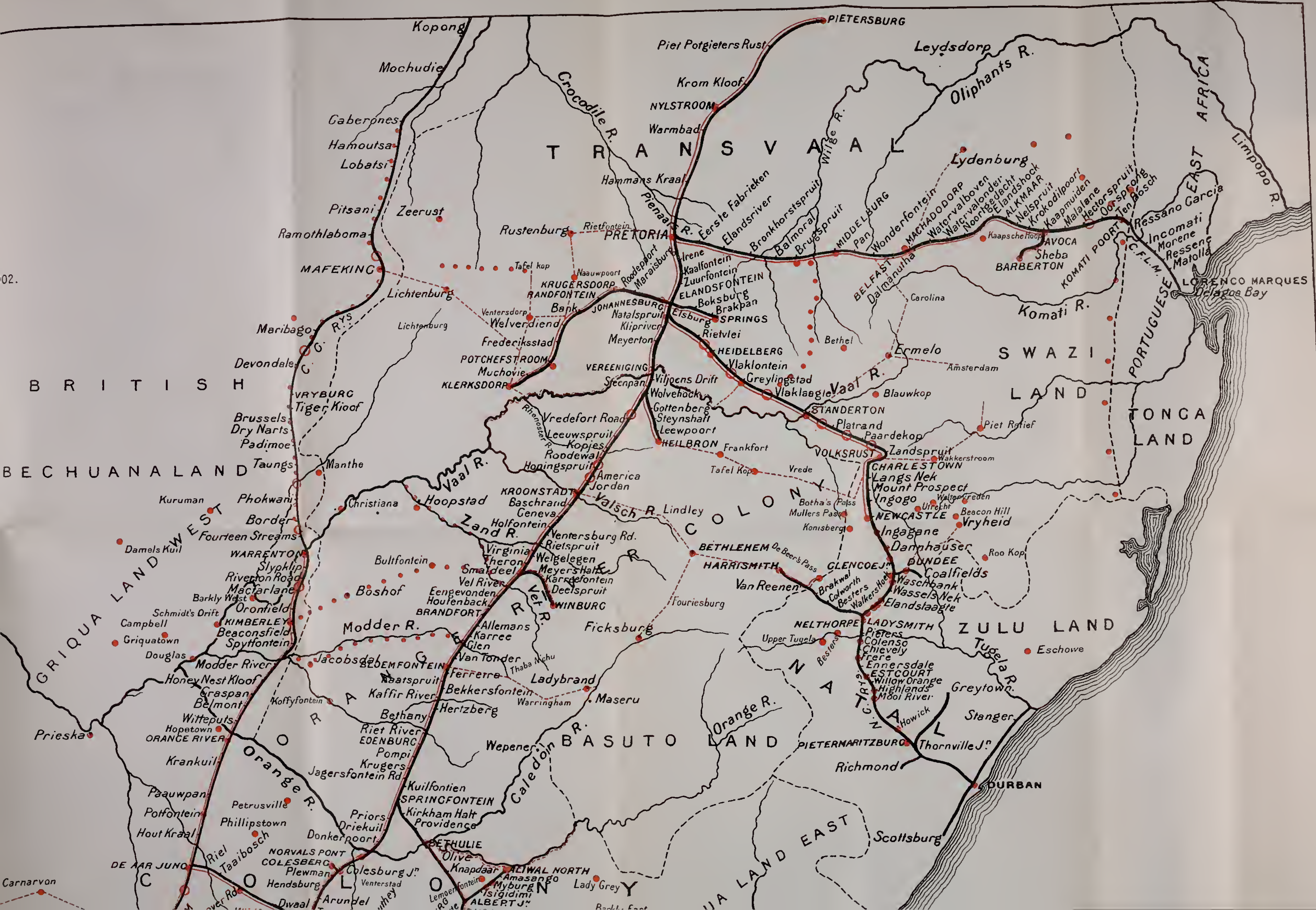
SHOWING BLOCKHOUSE LINES AND POSTS, AT END OF MARCH, 1902.

Scale 40 Miles - 1 Inch.

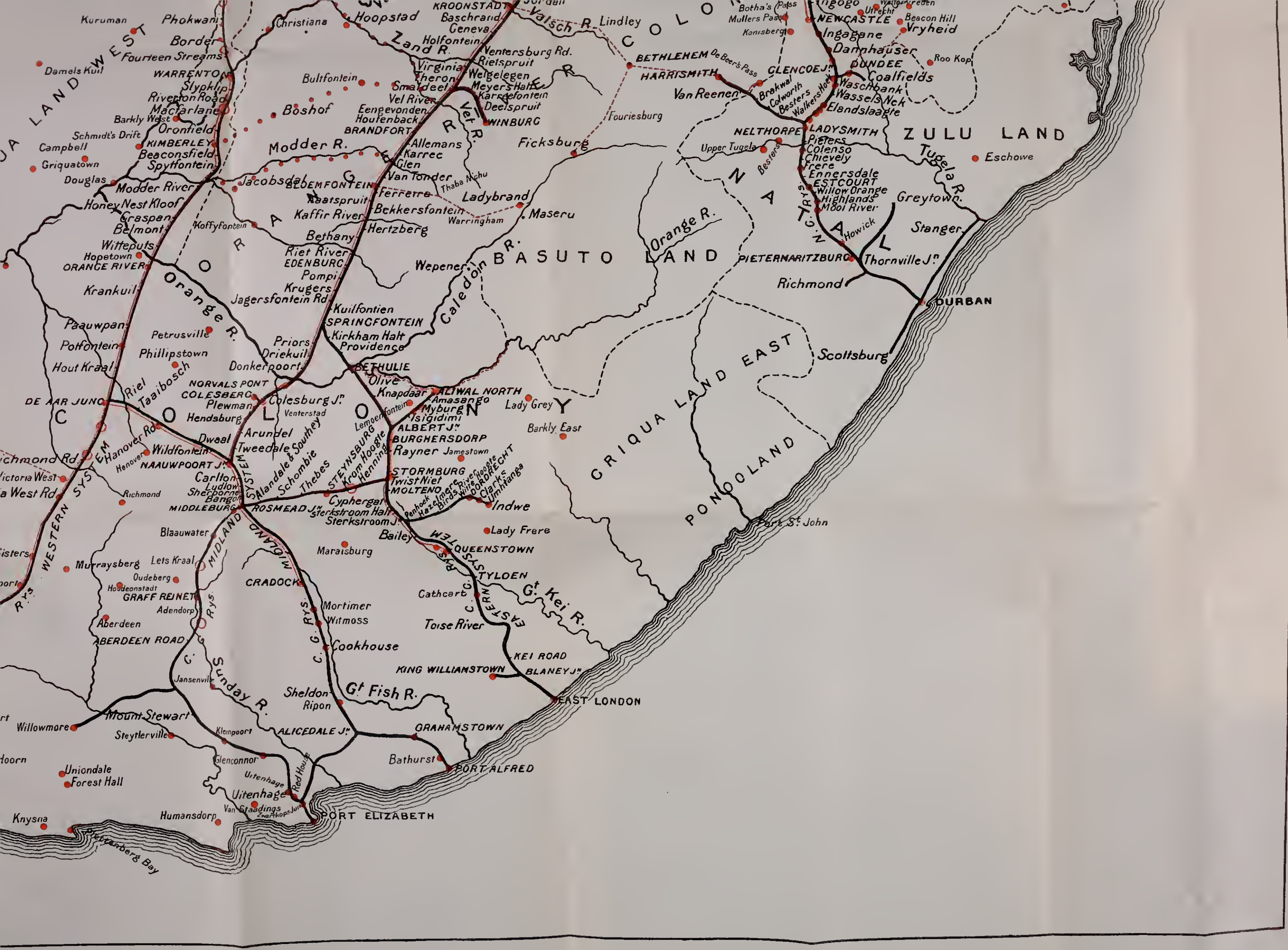
Line of Blockhouses along railways ——
D° across country - - - -
Stationary Garrisons and Posts ●
Armoured Trains ○

NOTE. The lines of Blockhouses are not necessarily shewn on the proper side of the Railway.

PLATE XVII.



02.
TRANSVAAL
BRITISH
BECHUANALAND
GRIQUA LAND WEST
ORANGE RIVER COLONY
BASUTO LAND
NATAL
ZULU LAND
SWAZI LAND
TONGA LAND
PORTUGUESE EAST AFRICA
COLONY
Kopong
Mochudie
Gaberones
Hamoutsa
Lobatsi
Pitsani
Zeerust
Ramothlaboma
MAFEKING
Lichtenburg
Maribago
Devondale
C. G. RYS.
VRYBURG
Tiger Kloof
Brussels
Dry Narts
Padimoe
Taungs
Manthe
Kuruman
Phokwani
Border
Fourteen Streams
Damels Kuil
WARRENTON
Slypklip
Riverton Road
Macfarlane
Barkly West
Orontfield
Schmidt's Drift
Campbell
KIMBERLEY
Beaconsfield
Spytfontein
Griquatown
Douglas
Modder River
Honey Nest Kloof
Graspan
Belmont
Witteputs
Hopetown
ORANGE RIVER
Prieska
Krankuil
Paauwpan
Potfontein
Hout Kraal
Petrusville
Phillipstown
DE AAR JUNC.
Riet
Taaibosch
Carnarvon
Koffyfontein
Christiana
Hoopstad
Bultfontein
Boshof
Jacobsdal
Modder R.
Vaal R.
Zand R.
Rustenburg
Rietfontein
PRETORIA
Tafel kop
Naauwpoort
KRUGERSDORP
RANDFONTEIN
Roodepoort
Maraisburg
Bank
JOHANNESBURG
Ventersdorp
Welverdiend
Lichtenburg
Fredeciksstad
POTCHEFSTROOM
Muchovie
KLERKSDORP
Natalspruit
Kliprivier
Meyerton
VEREENIGING
Steenpan
Viljoens Drift
Wolvehock
Gottenberg
Steynshaft
Leewpoort
HEILBRON
Rhenoster R.
Vredefort Road
Leeuwspruit
Kopjes
Roodewal
Honingspruit
America
Jordan
KROONSTADT
Baschrand
Geneva
Holfontein
Valsch R.
Lindley
Ventersburg Rd.
Virginia
Rietspruit
Theron
Welgelegen
Smaldeel
Meyers Halt
Karreefontein
Deelspruit
Vel River
Eenpevonden
Houtenback
BRANDFORT
WINBURG
Vet R.
Allemans
Karree
Glen
Van Tonder
Thaba N'chu
BLOEMFONTEIN
Ferreira
Kaatspruit
Bekkersfontein
Kaffir River
Bethany
Hertzberg
Warringham
Ladybrand
Maseru
Ficksburg
Fouriesburg
Riet River
EDENBURG
Pompi
Krugers
Jagersfontein Rd.
Wepener
Caledon R.
Kuilfontien
SPRINGFONTEIN
Kirkham Halt
Providence
Priors
Driekuil
Donkerpoort
Orange R.
NORVALS PONT
COLESBERG
Plewman
Colesburg J.n
Hendsburg
Venterstad
Divaal
Arundel
BETHULIE
Olive
Knapdaar
ALIWAL NORTH
Amasango
Myburg
Isigidimi
ALBERT J.n
Lemoenfontein
Lady Grey
Piet Potgieters Rust
PIETERSBURG
Krom Kloof
NYLSTROOM
Warmbad
Crocodile R.
Hammans Kraal
Pienaars R.
Irene
Kaalfontein
Zuurfontein
ELANDSFONTEIN
Boksburg
Brakpan
Elsburg
SPRINGS
Rietvlei
HEIDELBERG
Vlaklontein
Greylingstad
Vlaklaagte
Vaal R.
STANDERTON
Platrand
Paardekop
VOLKSRUST
Frankfort
Tafel Kop
Vrede
Eerste Fabrieken
Elandsriver
Bronkhorstspruit
Balmoral
Brugspruit
Wilge R.
MIDDELBURG
Pan
Wonderfontein
BELFAST
Dalmanutha
MACHADODORP
Waterval boven
Waterval onder
Noordbedacht
Elandshoek
ALKMAAR
Nelspruit
Krokodilpoort
Kaapmuiden
Malalane
Hectorspruit
Oorsprong
Ten Bosch
Kaapsche Hoop
AVOCA
Sheba
BARBERTON
KOMATI POORT
C.F.L.M.
Ressano Garcia
Incomati
Morene
Ressene
Matolla
LORENCO MARQUES
Delagoa Bay
Limpopo R.
Leydsdorp
Oliphants R.
Lydenburg
Carolina
Komati R.
Bethel
Ermelo
Amsterdam
Blauwkop
Piet Retief
Wakkerstroom
Zandspruit
CHARLESTOWN
Langs Nek
Mount Prospect
Ingogo
Utrecht
Weltevreden
NEWCASTLE
Beacon Hill
Vryheid
Ingagane
Dannhauser
DUNDEE
Roo Kop
Coalfields
Waschbank
Wassels Nek
Elandslaagte
Botha's Pass
Mullers Pass
Konisberg
BETHLEHEM
De Beer's Pass
HARRISMITH
GLENCOE J.n
Van Reenen
Brakwal
Colworth
Besters
Walkers Hoek
NELTHORPE
LADYSMITH
Upper Tugela
Besters
Pieters
Colenso
Chievely
Frere
Ennersdale
ESTCOURT
Willow Grange
Highlands
Mool River
N.G. RYS.
Howick
Greytown
Tugela R.
Eschowe
Stanger
PIETERMARITZBURG
Thornville J.n
Richmond
DURBAN
Scottsburg
ZULU LAND EAST


Kuruman
Phokwani
Christiana
Hoopstad
KROONSTADT
Baschrand
Geneva
Holfontein
Zand R.
Valsch R.
Lindley
Bothas Pass
Mullers Pass
Konisberg
NEWCASTLE
Utrecht
Beacon Hill
Vryheid
Ingagane
Dannhauser
DUNDEE
Roo Kop
Coalfields
Waschbank
Wasserbank
Wessels Nek
Elandslaagte
BETHLEHEM
De Beers Pass
HARRISMITH
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Brakwal
Colworth
Besters
Walkers Hoek
Van Reenen
Fouriesburg
Ficksburg
NELTHORPE
LADYSMITH
Upper Tugela
Pieters
Colenso
Chievely
Frere
Ennersdale
ESTCOURT
Willow Orange
Highlands
Mooi River
Howick
ZULU LAND
Eschowe
Tugela R.
Greytown
Stanger
NATAL
N.G. RYS.
PIETERMARITZBURG
Thornville J.
Richmond
DURBAN
Scottsburg
Orange R.
BASUTO LAND
Maseru
Ladybrand
Warringham
Wepener
Caledon R.
GRIQUA LAND EAST
PONDOLAND
Port St. John
Border
Fourteen Streams
Damels Kuil
WARRENTON
Slypklip
Riverton Road
Macfarlane
Barkly West
Orontfield
Schmidt's Drift
KIMBERLEY
Campbell
Beaconsfield
Griquatown
Spytfontein
Douglas
Modder River
Honey Nest Kloof
Graspan
Belmont
Witteputs
Hopetown
ORANGE RIVER
Krankuil
Paauwpan
Potfontein
Hout Kraal
DE AAR JUNC.
Richmond Rd.
Victoria West
Victoria West Rd.
Bultfontein
Boshof
Virginia
Theron
Smaldeel
Vel River
Eengevonden
Houtenback
BRANDFORT
Ventersburg Rd.
Rietspruit
Welgelegen
Meyers Halt
Karreefontein
Deelspruit
Vet R.
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Modder R.
Allemans
Karree
Glen
Van Tonder
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Lemoenfontein
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NORVALS PONT
COLESBERG
Plewman
Hendsburg
Colesburg J.
Venterstad
Arundel
Tweedale
Southey
Dwaal
Hanover Rd.
Hanover
Wildfontein
NAAUWPOORT J.
Carlton
Ludlow
Sherborne
Bangor
MIDDLEBURG
Richmond
Alandale
Schombie
Thebes
STEYNSBURG
Krom Hoogte
Henning
ALBERT J.
BURGHERSDORP
Rayner
Jamestown
STORMBURG
Twist Niet
MOLTENO
Penhoek
Hazelmere
Birds River
Wite Hoogte
DORDRECHT
Clarks
Umhlanga
Indwe
ROSMEAD J.
Cyphergat
Sterkstroom Halt
Sterkstroom J.
Bailey
Lady Frere
QUEENSTOWN
Maraisburg
Blaauwater
COLONY
WESTERN SYSTEM
MIDLAND SYSTEM
MIDLAND
Murraysberg
Lets Kraal
Oudeberg
Houdeonstadt
GRAFF REINET
Adendorp
Aberdeen
ABERDEEN ROAD
CRADOCK
Mortimer
Witmoss
Cookhouse
C.G. RYS.
Cathcart
Toise River
TYLOEN
EASTERN SYSTEM
Gt. Kei R.
KEI ROAD
BLANEY J.
KING WILLIAMSTOWN
EAST LONDON
Jansenville
Sunday R.
Sheldon
Ripon
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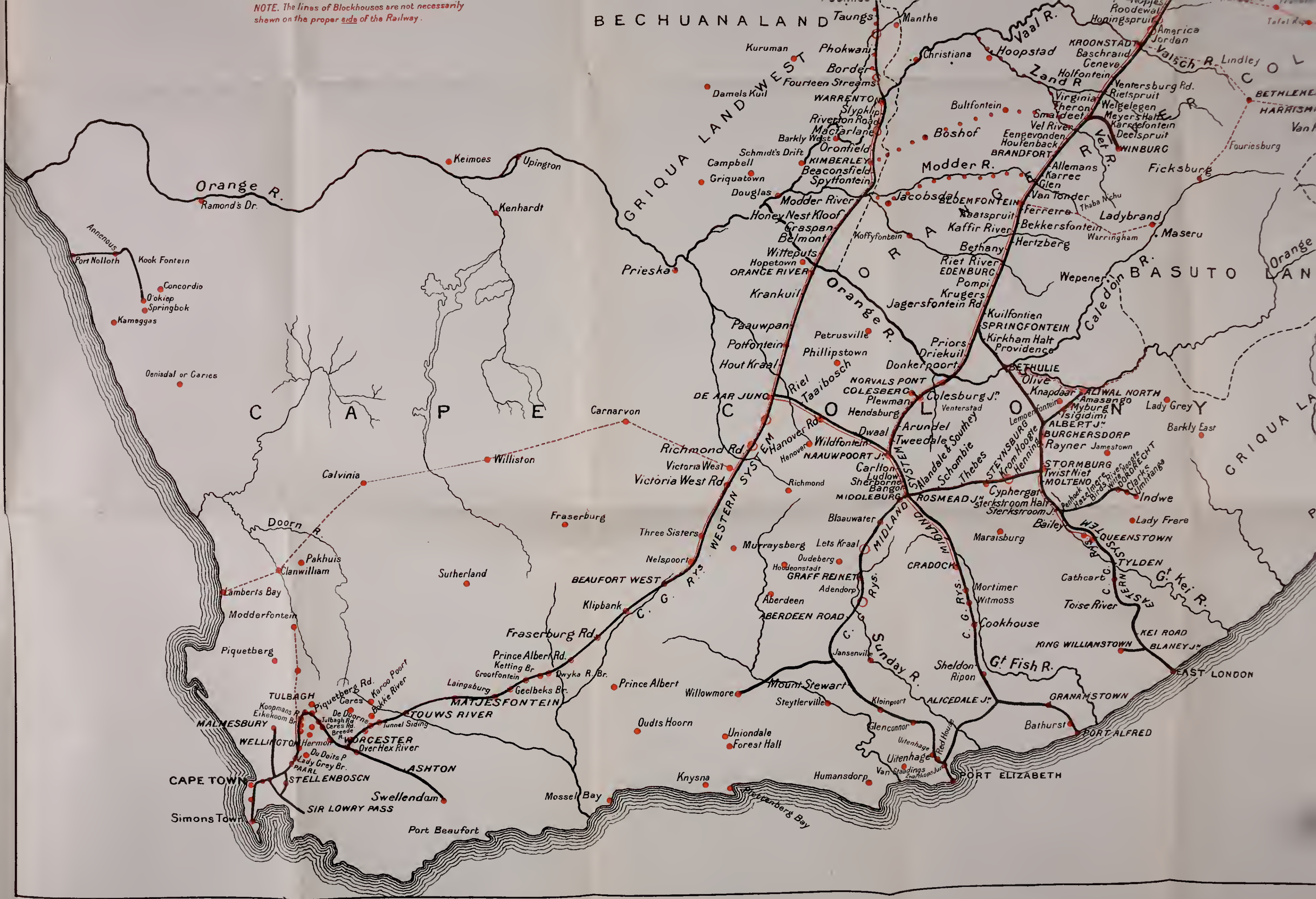
ALICEDALE J.
GRAHAMSTOWN
Bathurst
PORT ALFRED
Willowmore
Mount Stewart
Steytlerville
Kleinpoort
Glenconnor
Uitenhage
Red House
Van Staadens
Zwartkops Junc.
PORT ELIZABETH
Uniondale
Forest Hall
Knysna
Humansdorp
Plettenberg Bay
GRIQUA LAND WEST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